U.S. Army Corrosion Summit 2009

Clearwater Beach, FL

SCHOOL OF ENGINEERING AND MINES
UNIVERSITY OF NORTH DAKOTA, GRAND FORKS

Chemically accelerated vibratory surface finishing (CAVSF)

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Background

University of North Dakota - UND

* Founded in 1883 - 6 years before statehood.
* 13,000 students in 193 fields of study.

School of Engineering and Mines - SEM

* 1889 made the Engineering College at UND.
* Programs include: Chemical, Civil, Electrical, Geological, and Mechanical Engineering.

Engineered Surfaces Center - ESC

* About 3 years.
* Director, 3 FT Engineers and expanding.
* 2 PT Faculty.
* 1 PT Technician & OA.
* 6 PT Students

Content

- Introduction (Equipment – General – Test samples)
- Basics (Material removal – Roughness changes – Shear stress removal – Temperature increase – Sample distribution – Different media)
- End-roughness and micro structure of different C-steels
- Material removal and roughness changes versus the amount of treatment solution in the bowl
- Material removal and roughness changes versus pH
- Comparing the performance of a commercially available acid treatment solution with 0.5 M Ammonium bioxalate solution

Large vibratory bowl with 1.16 m inner diameter and a dosing station in the background for continuous flow of chemicals through the bowl

Small vibratory bowl with 0.28 m inner diameter filled with 4 kg of large ceramic media.

Chemically accelerated vibratory surface finishing (CAVSF)

Typical Process:

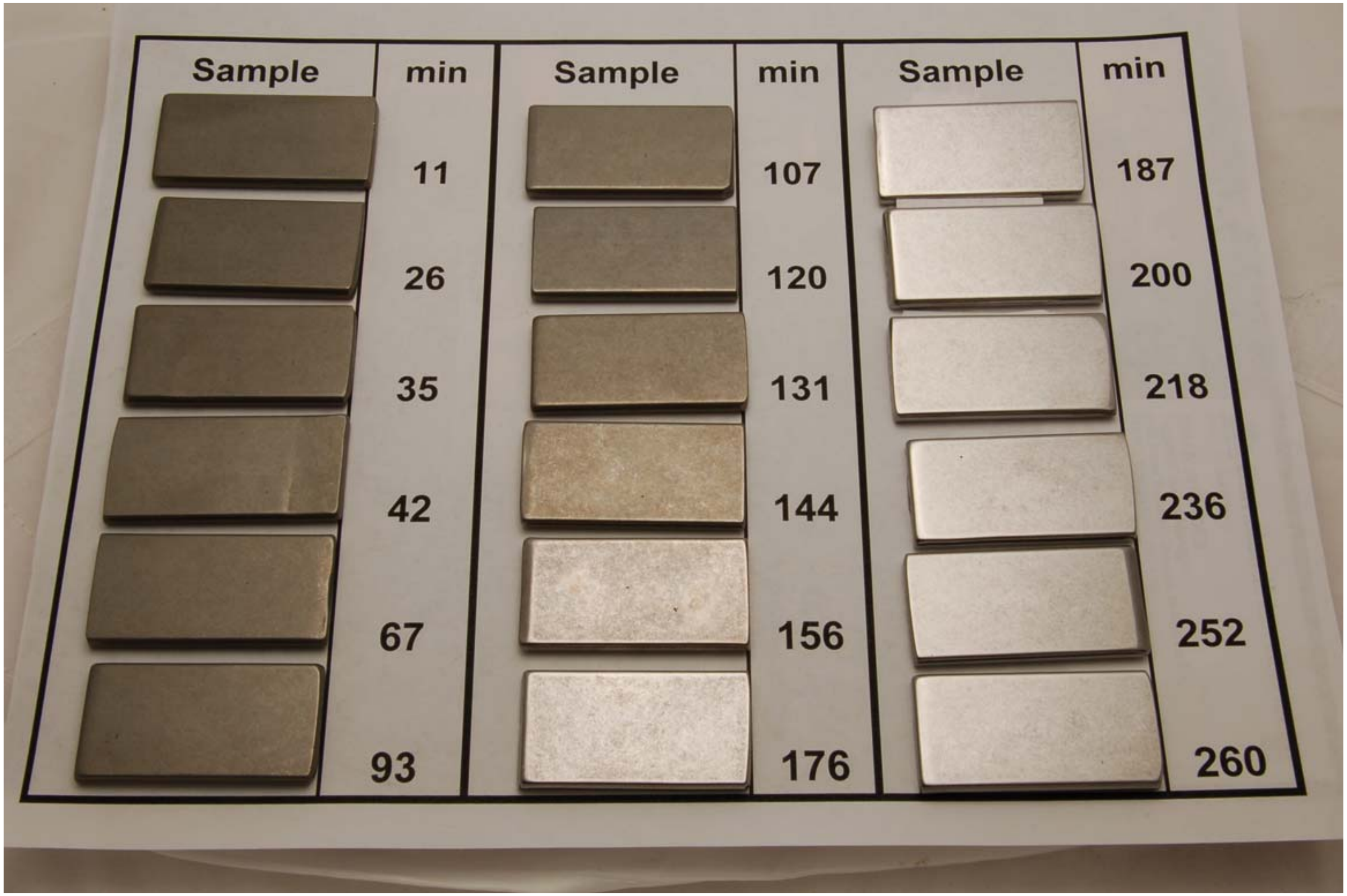
- 2 hours acid treatment
- 15 minutes water rinse
- 2 hours burnishing

Typical Result:

- The average surface roughness of for example helicopter gear teeth goes down from 16 to 2 micro-inches without impairing the geometry – less than 200 micro-inches removed.

Benefits: Less friction and stress at the mating surfaces resulting in

- No run-in time
- Lower operation temperature
- 300 to 400 % longer fatigue lifetime
- Reduced downtime
- Less noise, less vibration
- Higher energy efficiency
- Lower weight in new designs
- Overall lower costs

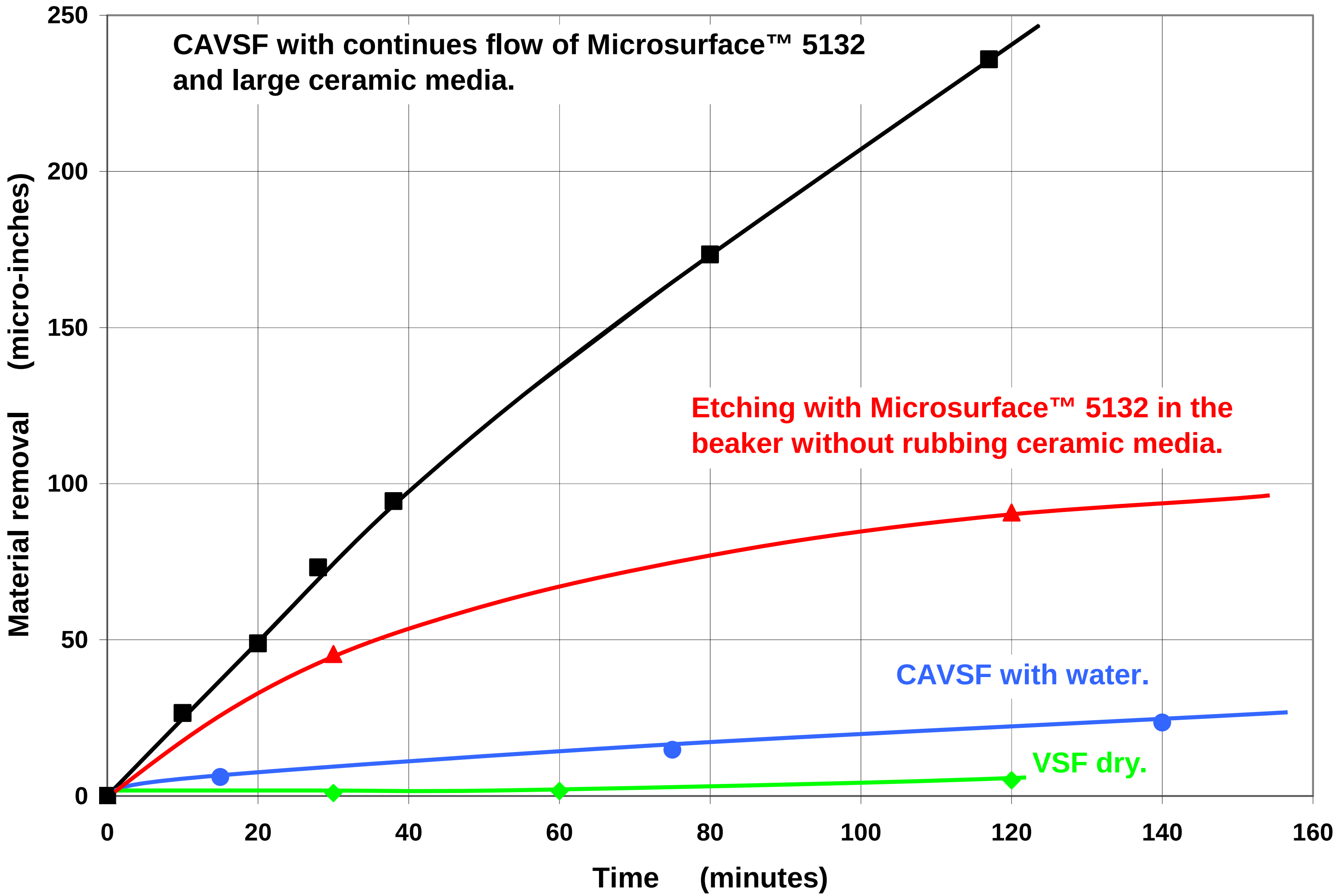


Visual appearance of strip steel test pieces during the CAVSF process.

0-120 minutes = acid treatment

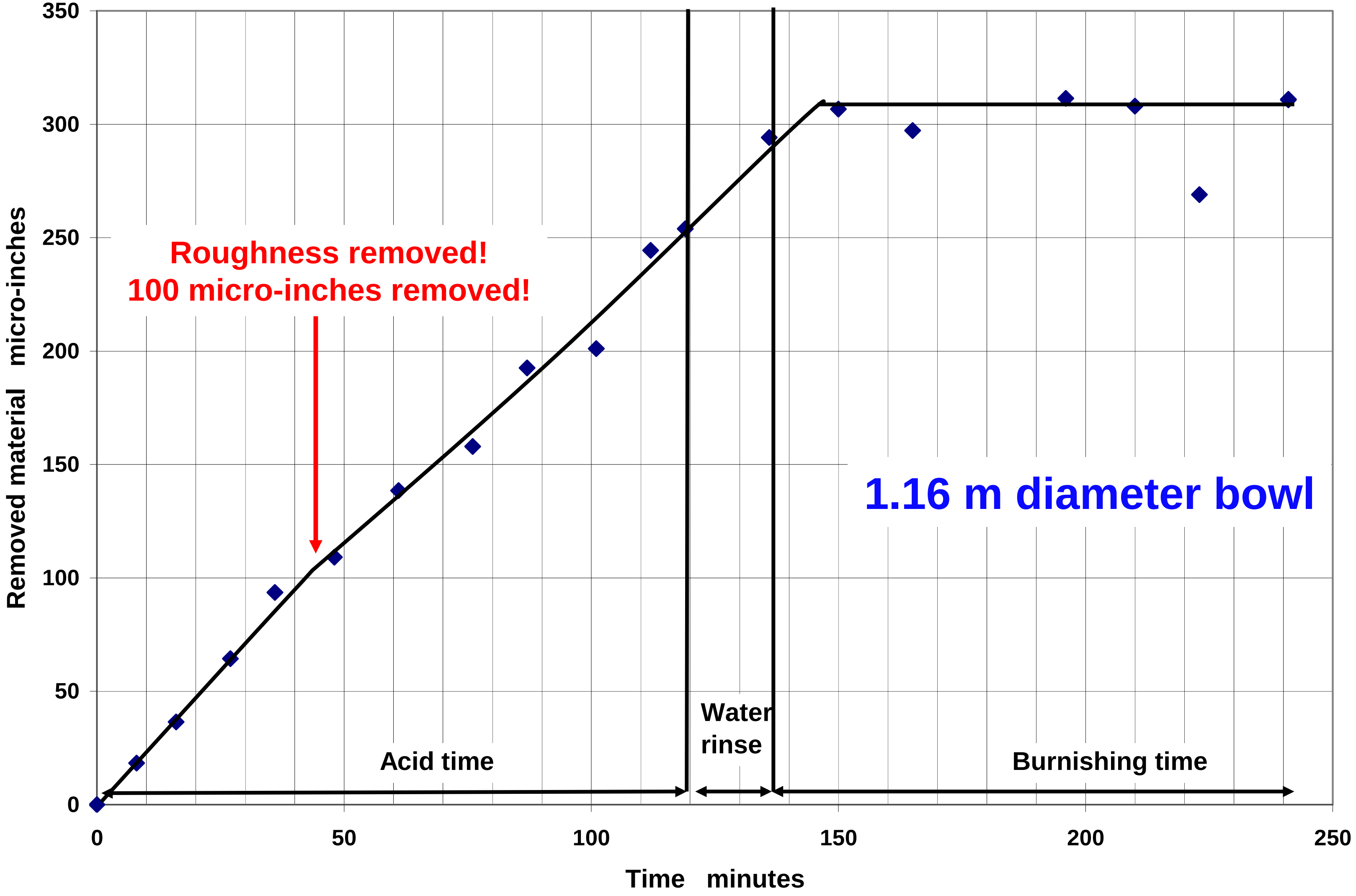
120-135 minutes = water rinse

135-260 minutes = burnishing

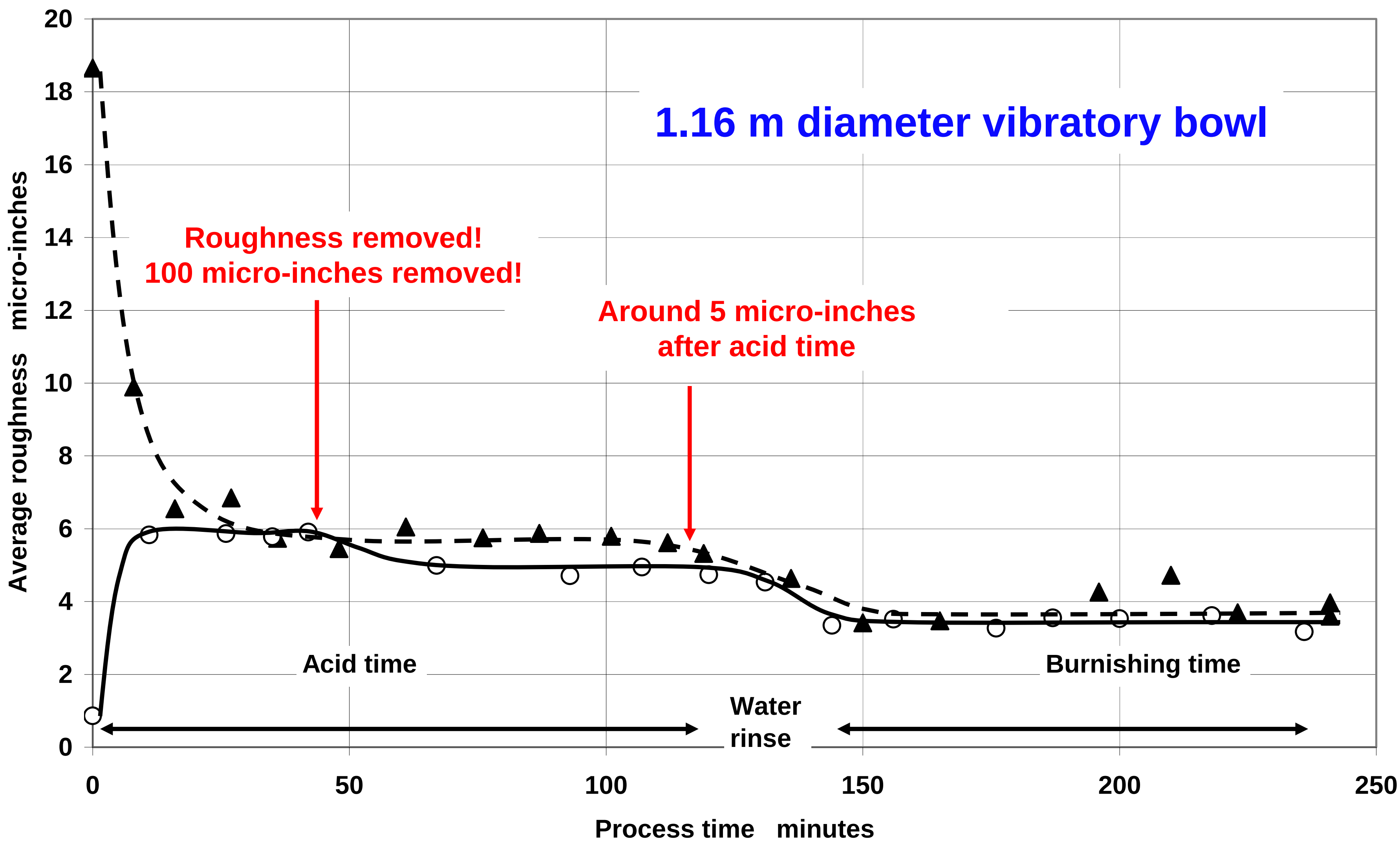


Material removal on Pyrowear 53™ during different processes versus time.

Material removal of strip steel pieces versus CAVSF time



Average roughness of strip steel pieces versus CAVSF time

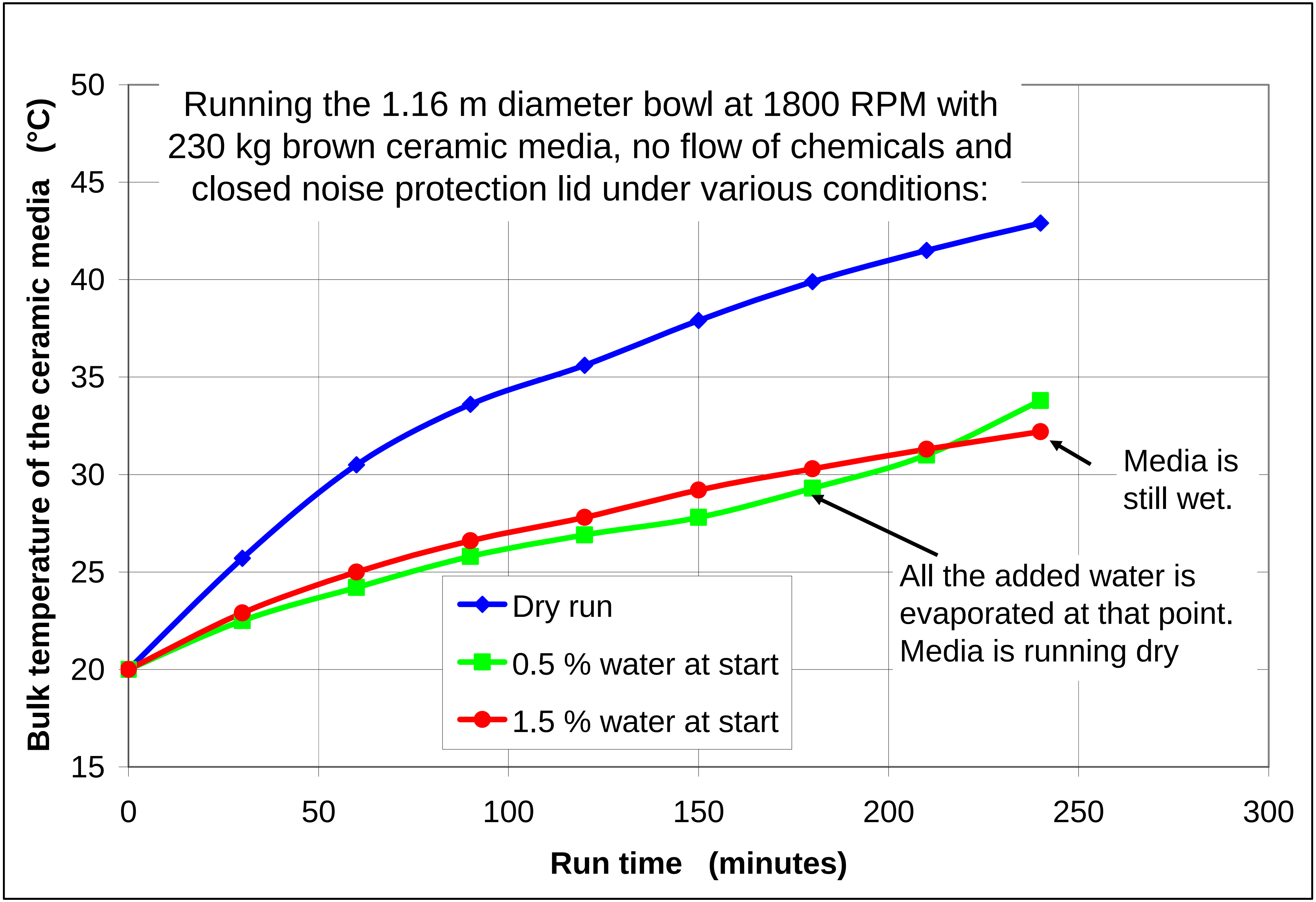


Results of surface stress analysis by Bruker

	Sample	σ_{11}	σ_{22}	σ_{12}	σ_{I}	σ_{II}
As ground	11	-499±80	-211±82	-184±199	-588	-121
After acid treatment	5	-441±82	-375±79	-110±193	-523	-292
After CAVSF	10	-412±87	-427±85	-7±199	-440	-400

The stress unit is MPa

- **σ_I and σ_{II} are the transformed stress values with all shear stress vanished.**
- **The σ_I and σ_{II} indicates the distribution of the stress. The closer values means the stress is more equally distributed along each direction.**
- **With the CAVSF, the shear stress was removed and the distribution of compressive stress becomes much more uniform.**

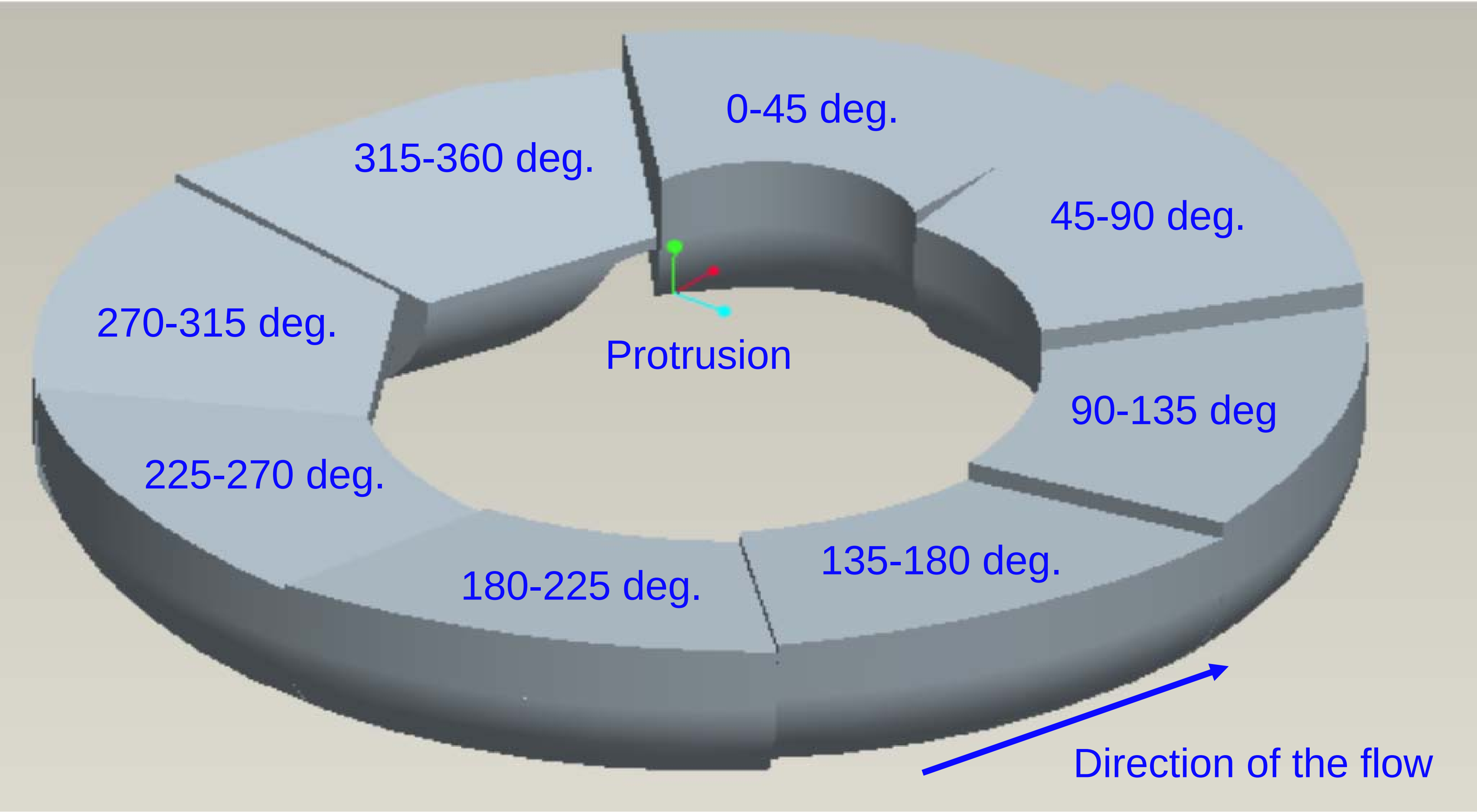

Running the 1.16 m diameter bowl at 1800 RPM with 230 kg brown ceramic media, no flow of chemicals and closed noise protection lid under various conditions:
Bulk temperature of the ceramic media (°C)
Run time (minutes)
50
45
40
35
30
25
20
15
0
50
100
150
200
250
300
Dry run
0.5 % water at start
1.5 % water at start
Media is still wet.
All the added water is evaporated at that point. Media is running dry

100 strip steel samples arranged for the distribution test

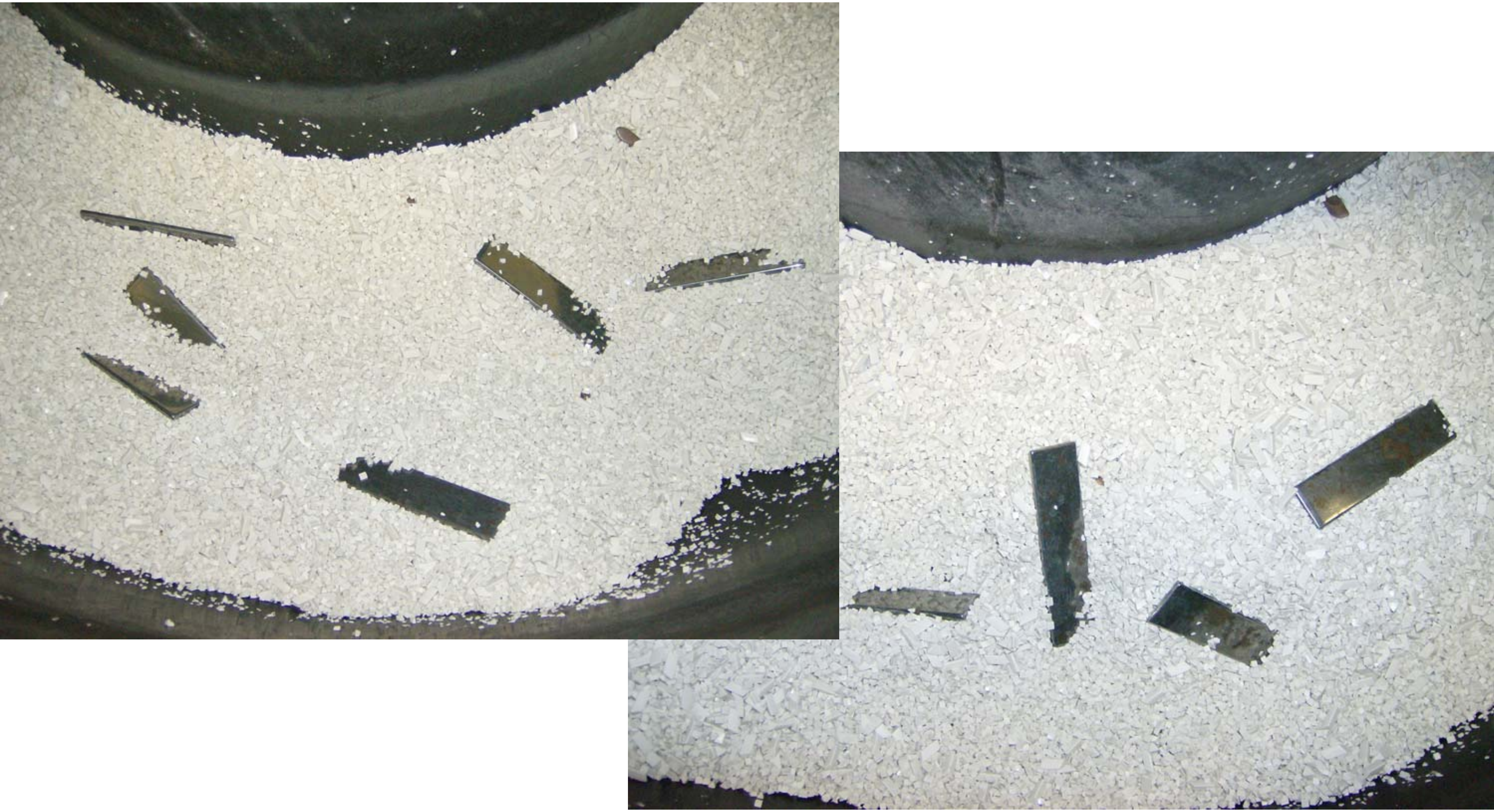
Starting the distribution test

Running the distribution test

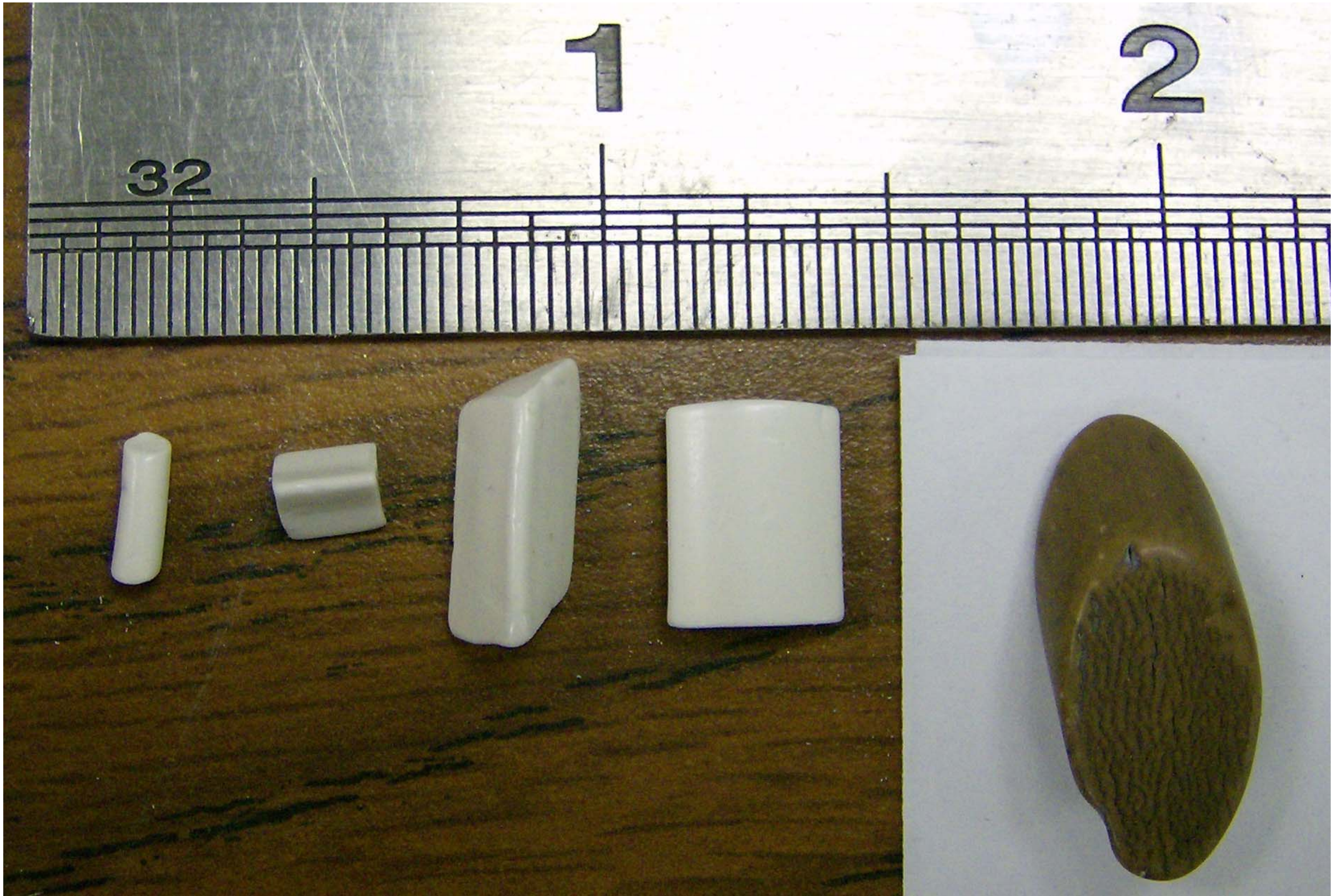
Drawing of the media bulk in the 1.16 m bowl



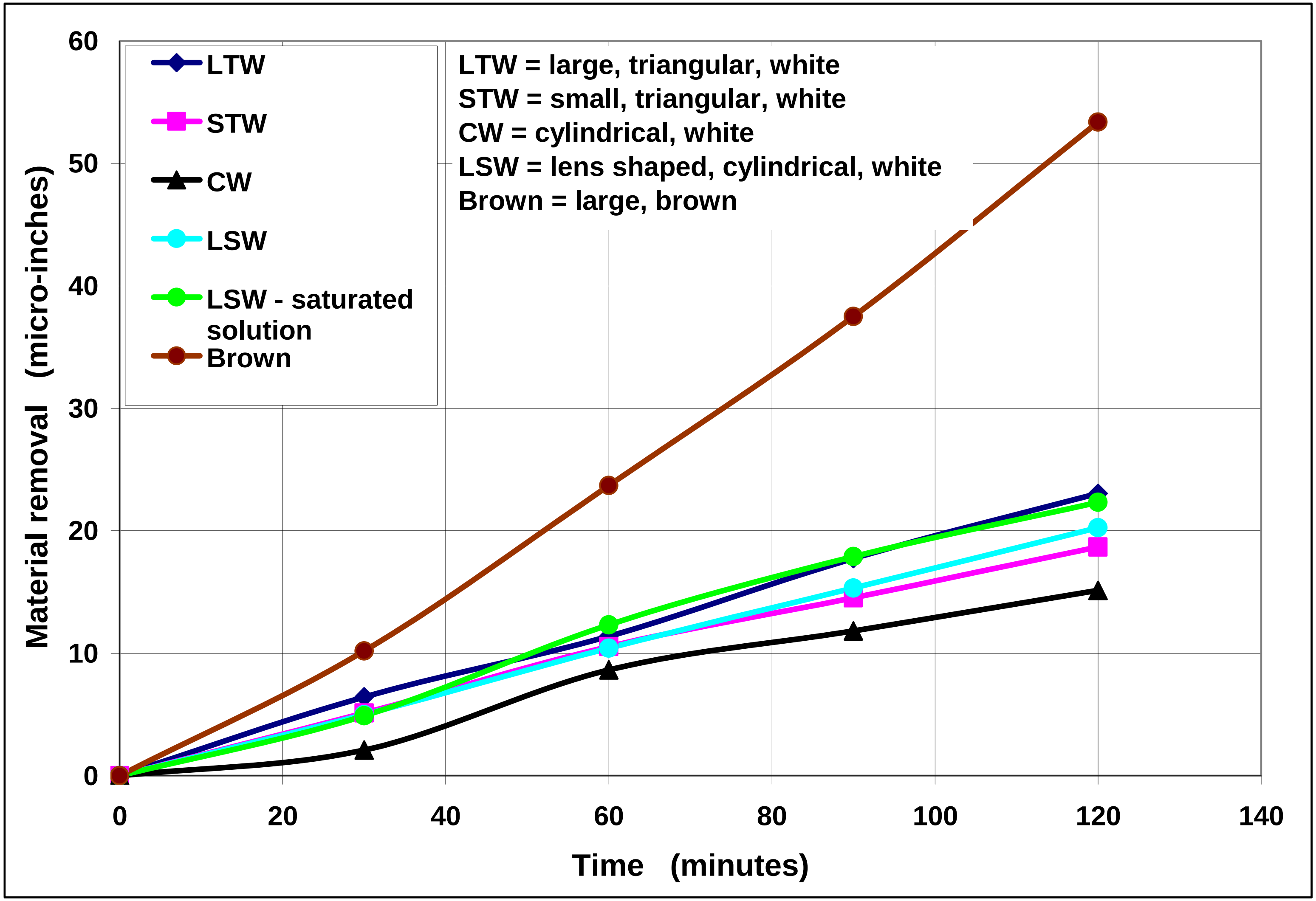
Digging out the samples and measuring the location and orientation

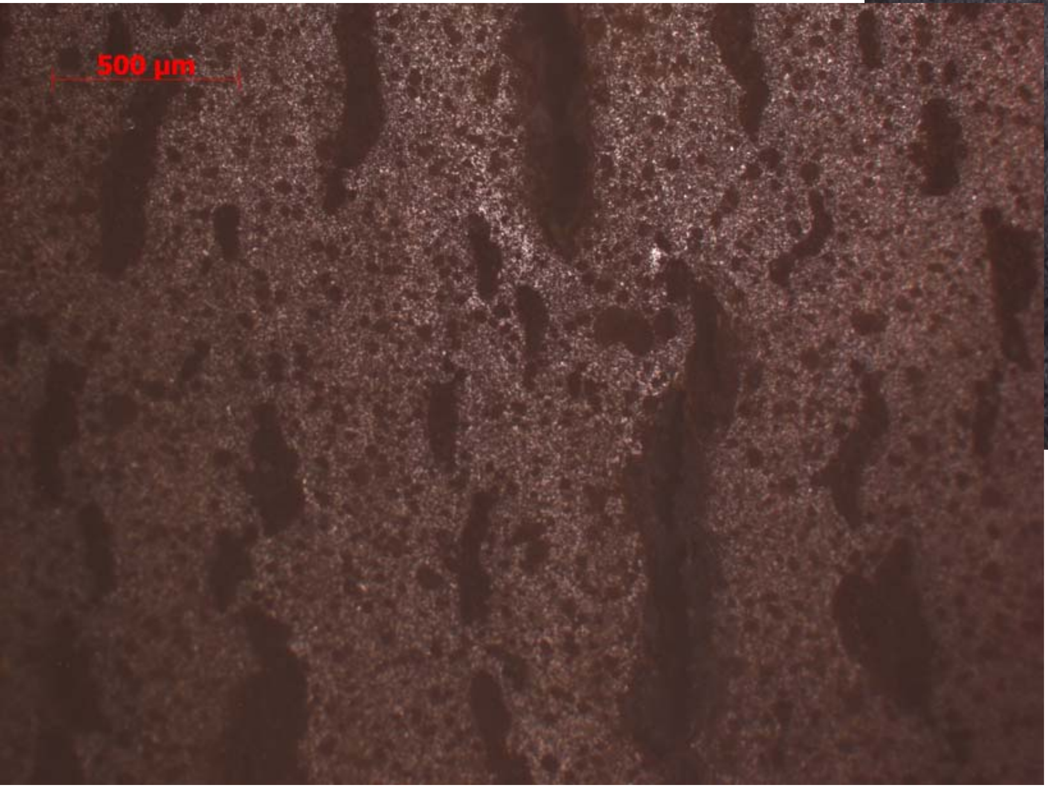


Different media pieces

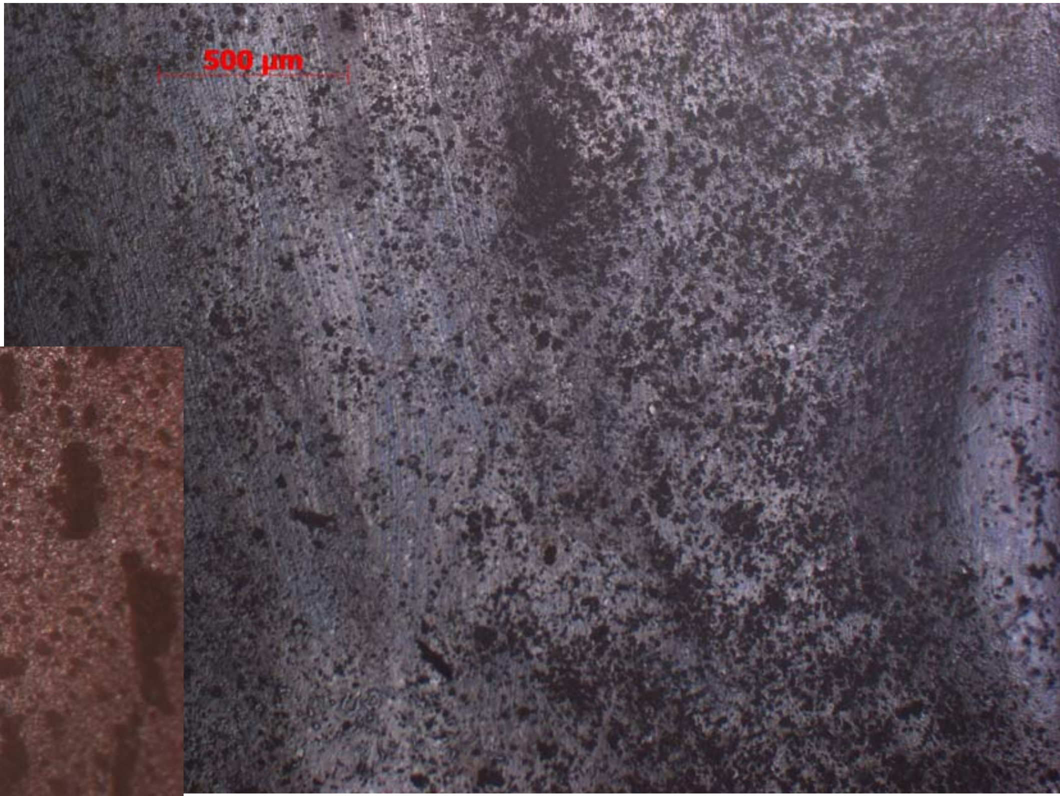


Material removal versus acid time with 0.27 M oxalic acid, 0.17 M ammonium oxalate and with different media.





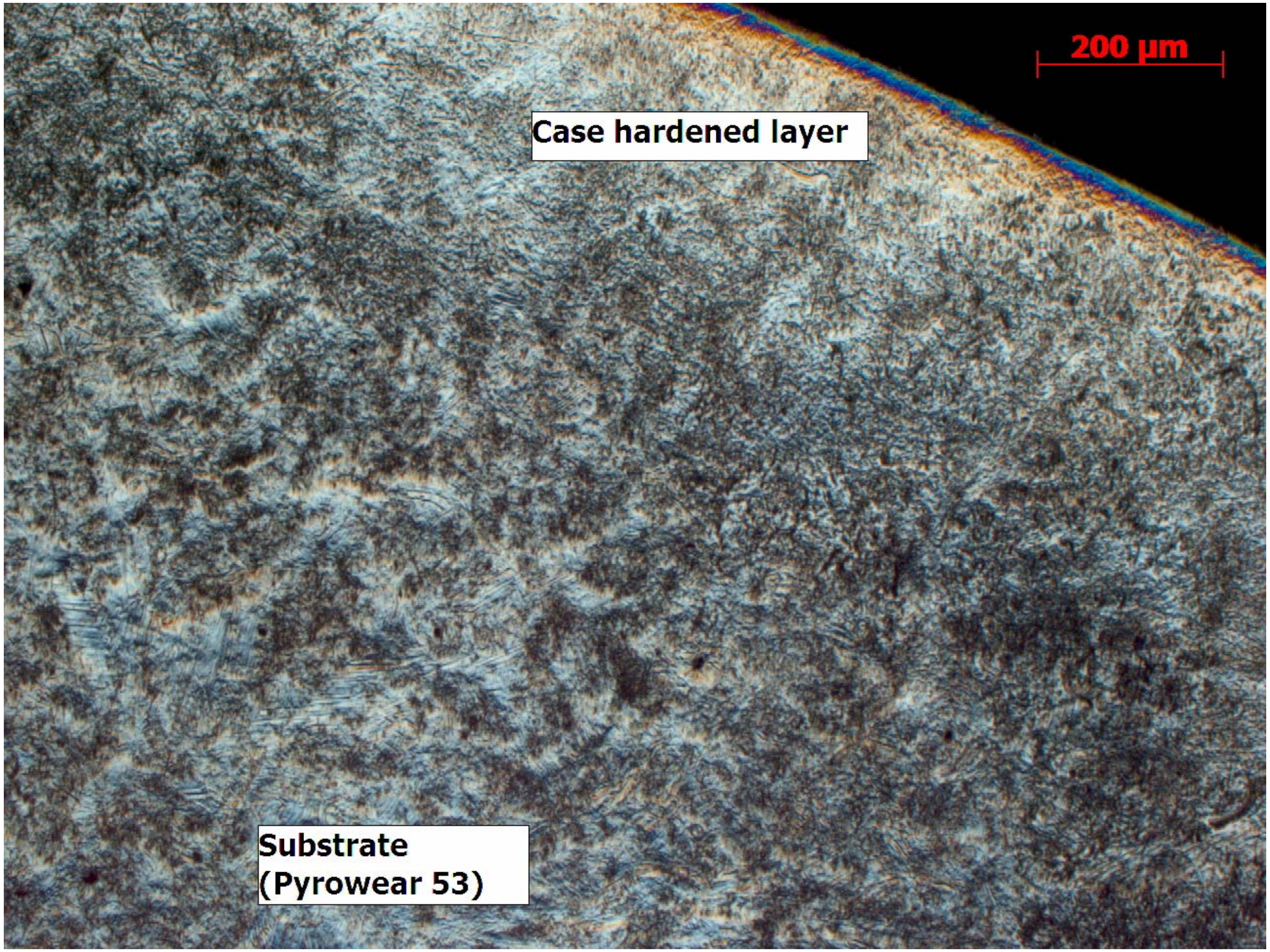
Brown media (top side)



White media

Media characteristics

Media	Bulk density	Max. liquid per load (2.2 L)	2/3 Max	Area per load (2.2 L)	Water thickness
Brown	1808 g/L	60 mL	40 mL	967877 mm^2	41.3 µm
White Large Triangle	1746 g/L	53 mL	35 mL	1403172 mm^2	24.9 µm
White Small Triangle	1622 g/L	100 mL	67 mL	2545960 mm^2	26.3 µm
White Circular Cylinder	1584 g/L	104 mL	69 mL	2906367 mm^2	23.7 µm
White Lens Cylinder	1726 g/L	72 mL	48 mL	1742464 mm^2	27.5 µm



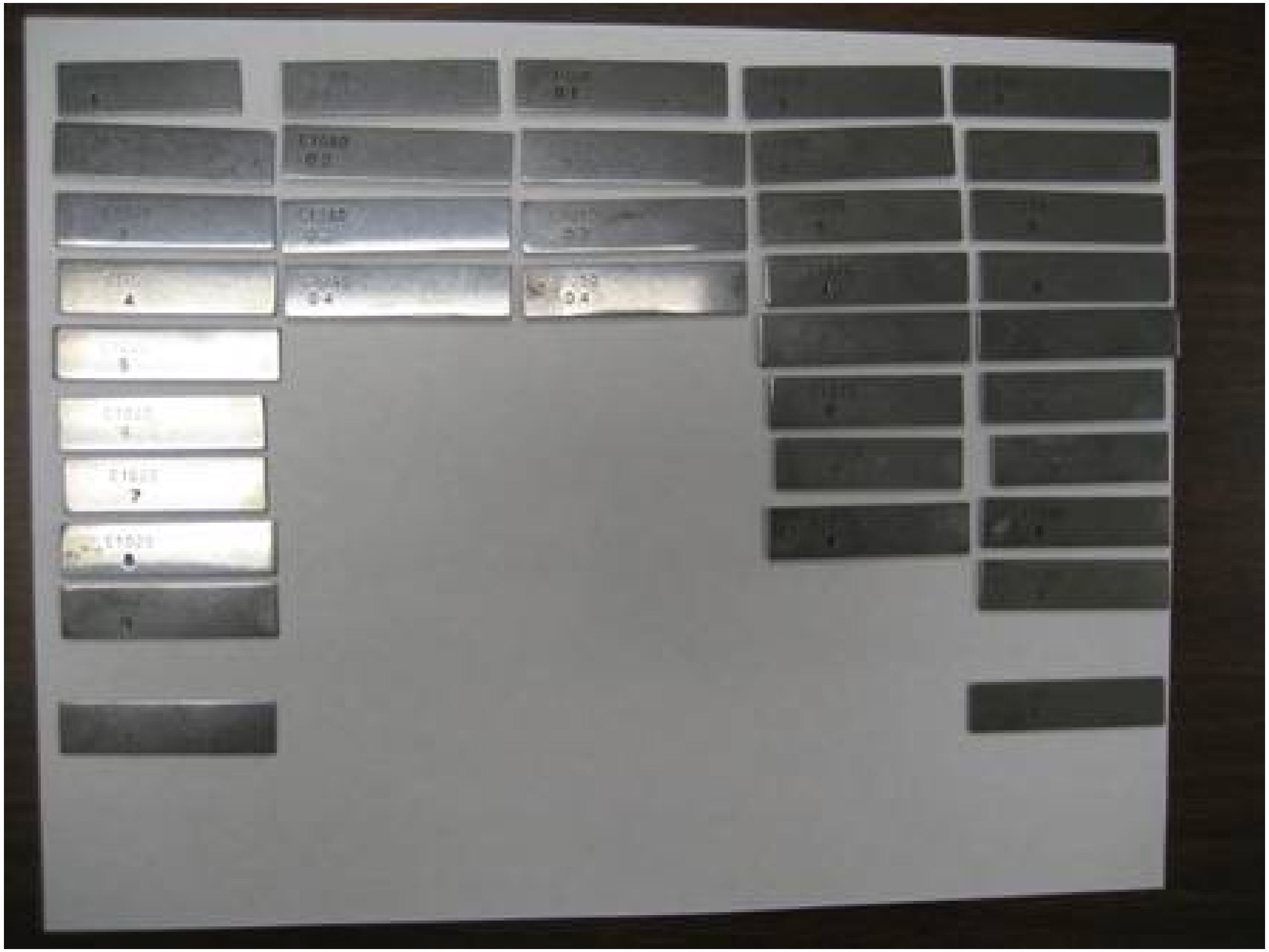
Cut Pyrowear 53™ sample with super-finished surface. The case hardened layer is smoother (Ra = 3 micro-inches (0.076 µm)) than the substrate (Ra = 7 micro-inches (0.18 µm)). CAVSF reveals the microstructure of the surface through etching.

Reasons for thermodynamic differences in the local etching rates

- Components are unevenly distributed
- Crystal size may differ
- Grain boundaries are different than the grain itself
- Failure in the crystal structure leads to tension in the lattice
- Crystal structure (martensite has a 1.7 kJ per mol higher free energy than ferrite)
- Grains are often randomly oriented. Different lattice planes are exposed during cutting which creates atoms surrounded by 6 atoms or 4 atoms or …
- Atoms in tips and edges of a crystal are only loosely connected.

C 1020 C 1040 C 1050 C 1075 C 1095

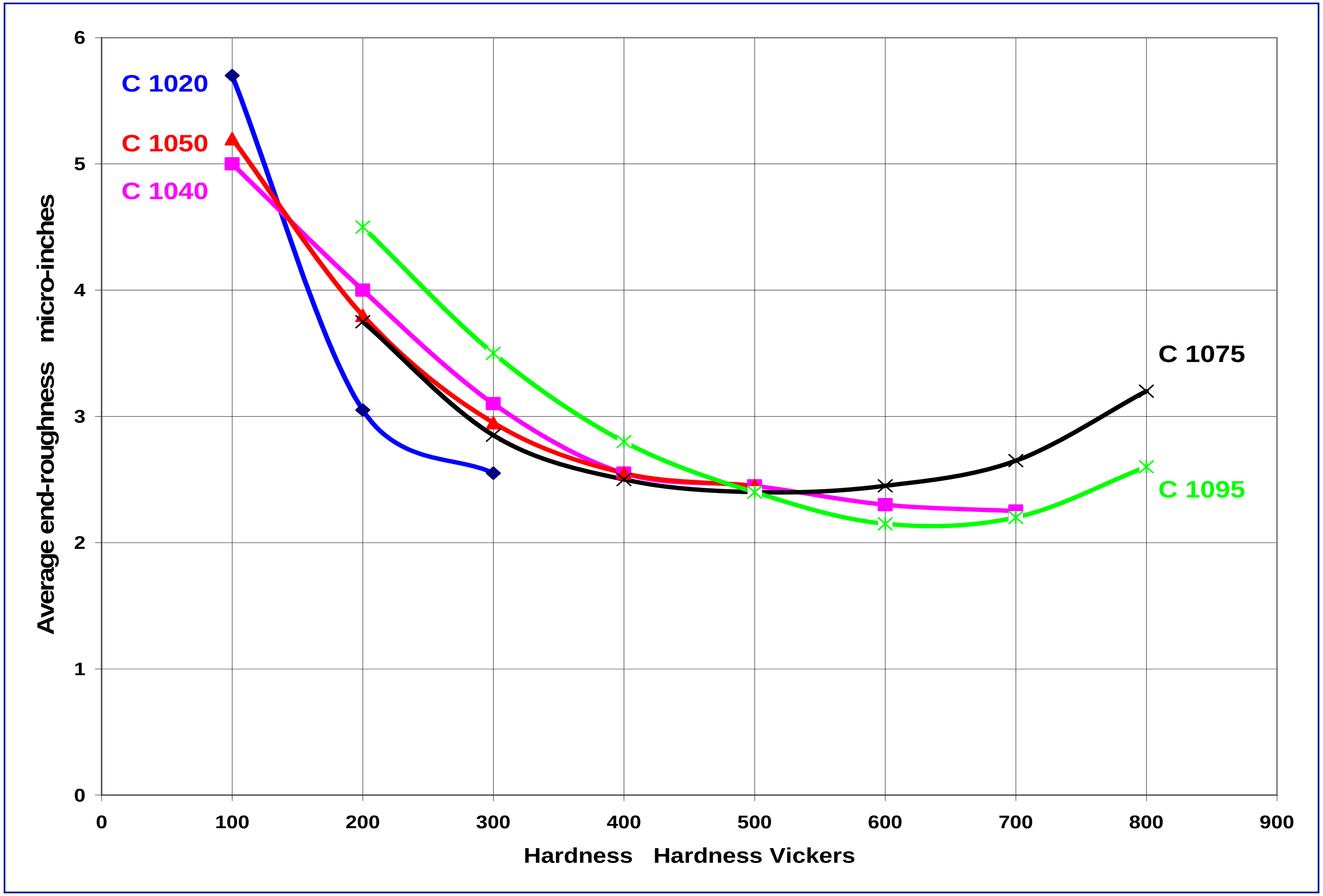
Tested carbon steels



Used heat treatments:

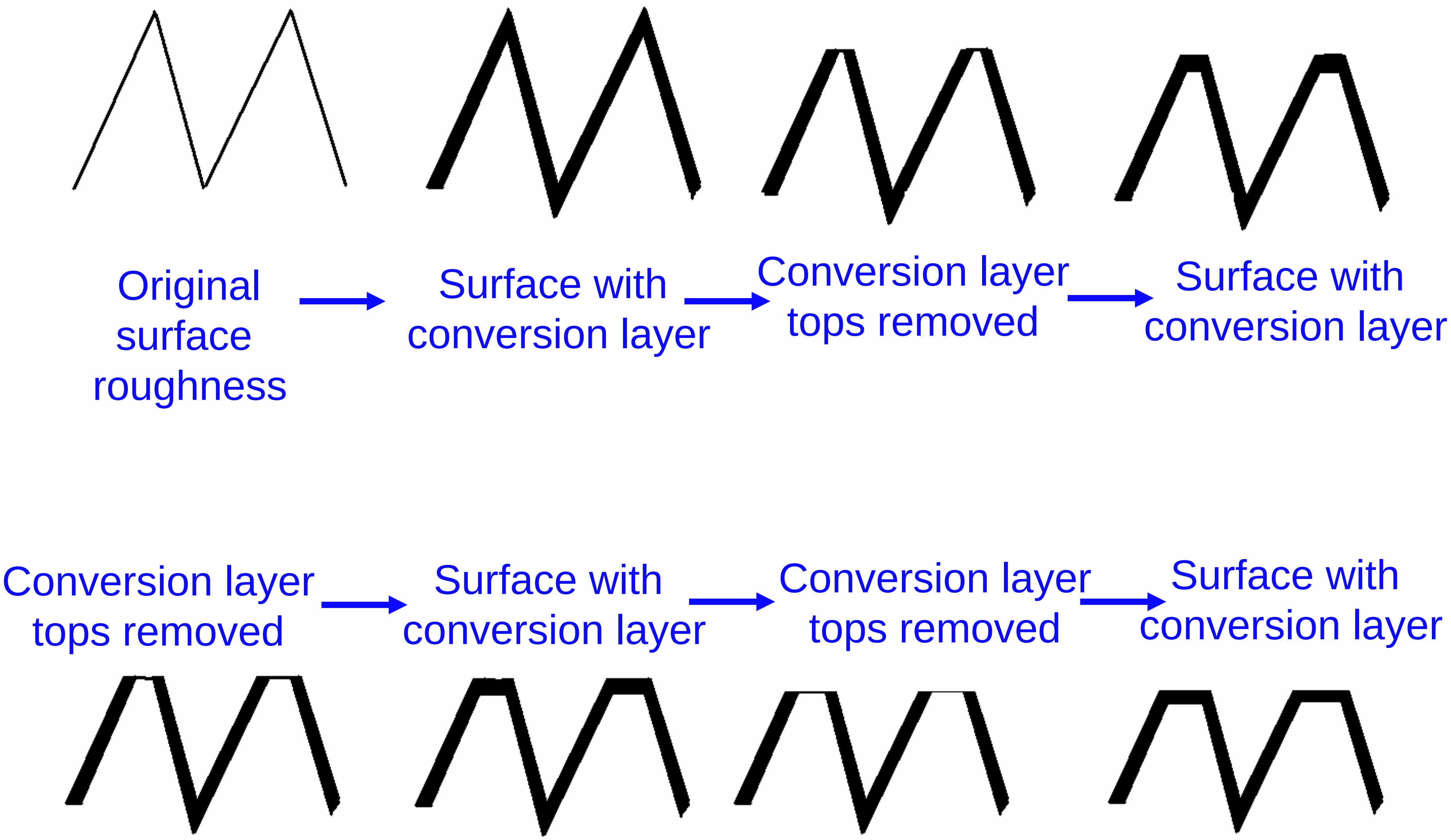
As received (annealed)
Air cooled
Cooled between plates
Cooled with wet towels
Water quenched (Wq)
Wq + heat treatm. 1
Wq + heat treatm. 2
Wq + heat treatm. 3
Annealed
Annealed (diff. temp.)
Heat treatment not defined

Carbon steel test samples with different carbon contents and different heat treatments to create different hardnesses and a variety of grains (ferrite, cementite, pearlite, bainite, martensite, retained austenite …)



Average end-roughness versus hardness for C-steels with different carbon contents and heat treatments.

Mechanism of the CAVSF



Possible chemical reactions during acid treatment

(1) $2\ H^{+}_{(aq)} + Fe_{(s)} \rightarrow Fe^{++}_{(aq)} + H_{2(g)}$

(2) $Fe^{++}_{(aq)} + 2\ H_2O \rightarrow Fe(OH)_{2(s)} + 2\ H^{+}_{(aq)}$

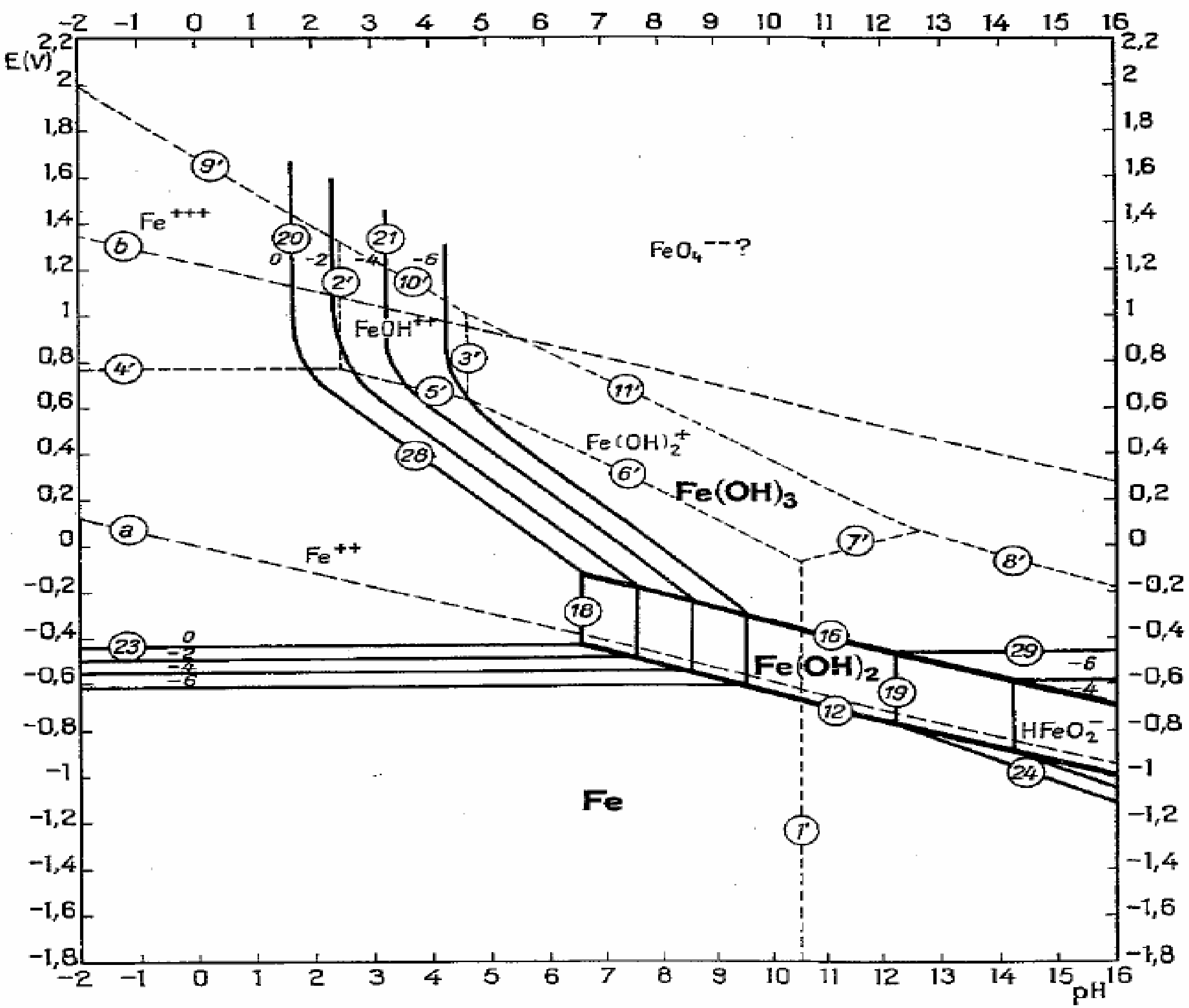
(3) $4\ Fe^{++}_{(aq)} + O_2 + 2\ H_2O \rightarrow 4\ Fe^{+++}_{(aq)} + 4\ OH^{-}$

(4) $3\ Fe^{++}_{(aq)} + 3\ (COOH)_{2(aq)} \rightarrow 3\ Fe(COO)_{2(s)} + 6\ H^{+}_{(aq)}$

(5) $2\ Fe^{+++}_{(aq)} + Fe_{(s)} \rightarrow 3\ Fe^{++}_{(aq)}$

(4+5) $2\ Fe^{+++}_{(aq)} + Fe_{(s)} + 3\ (COOH)_{2(aq)} \rightarrow 3\ Fe(COO)_{2(s)} + 6\ H^{+}_{(aq)}$

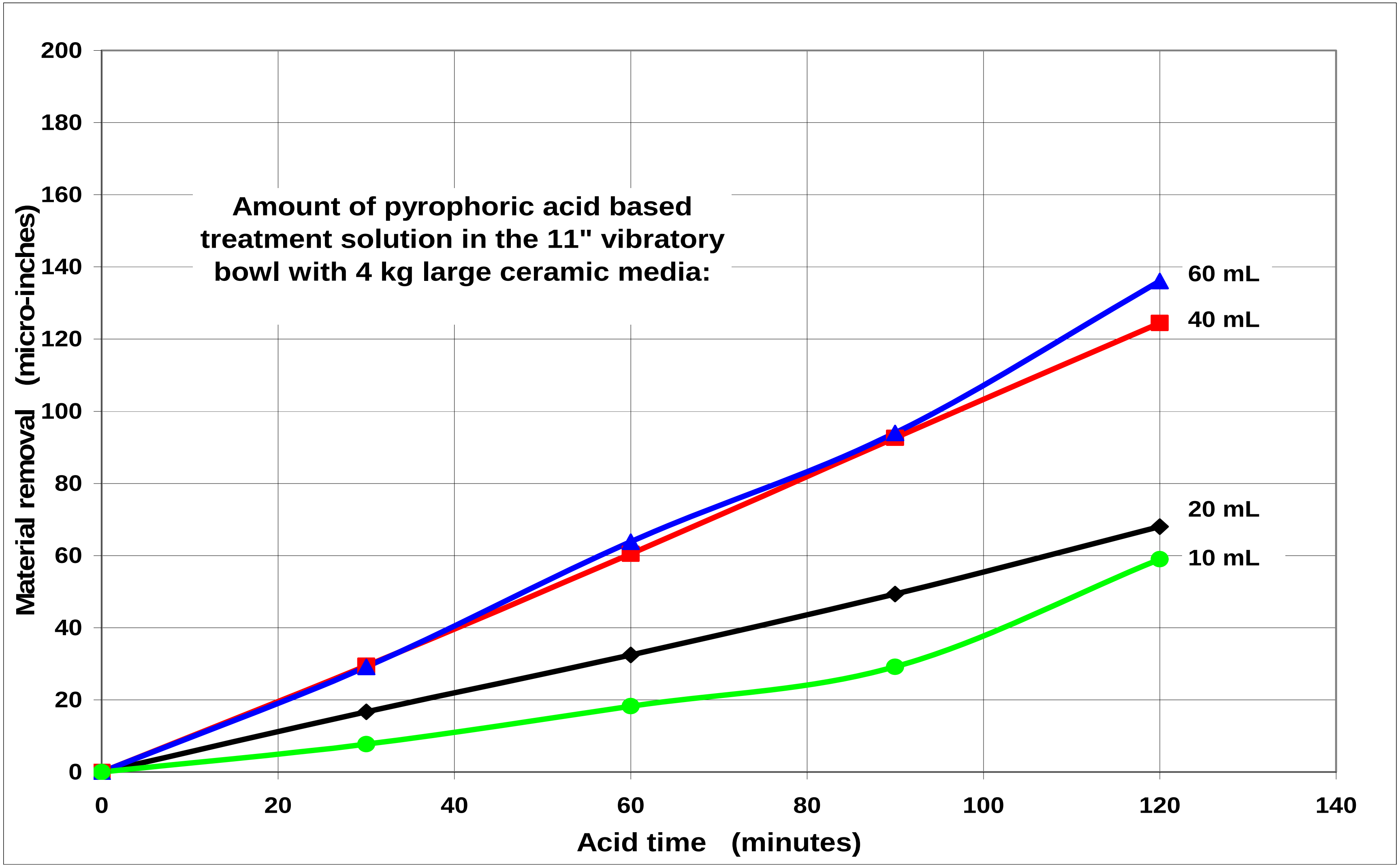
Potential – pH equilibrium diagram



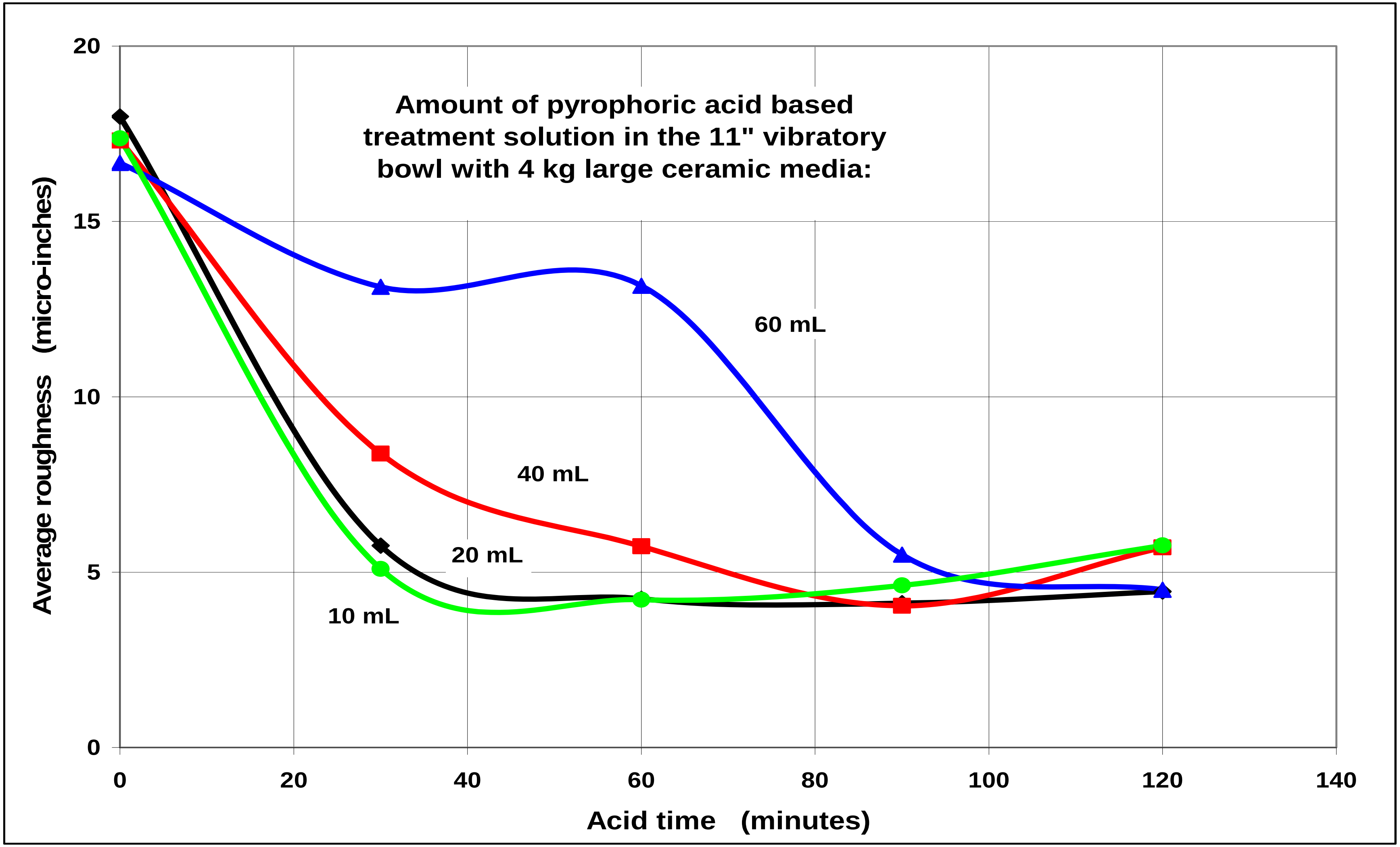
System:
Iron – Water
at 25 deg. C
(considering
as solid
substances only
Fe, $Fe(OH)_2$,
and $Fe(OH)_3$)

From M. Pourbaix
and N. de Zoubov

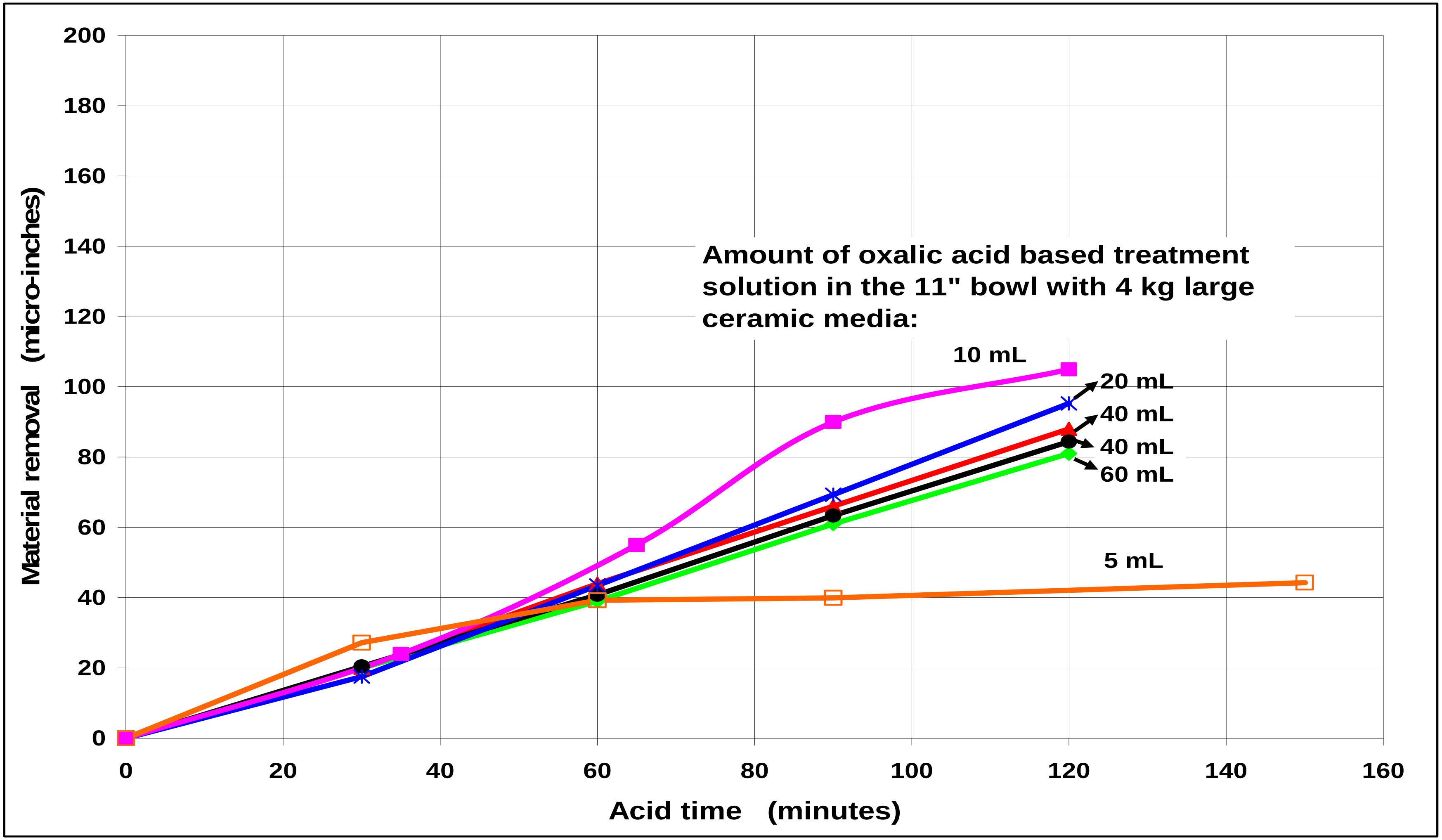
Material removal versus acid time for different amounts of pyrophosphoric acid.



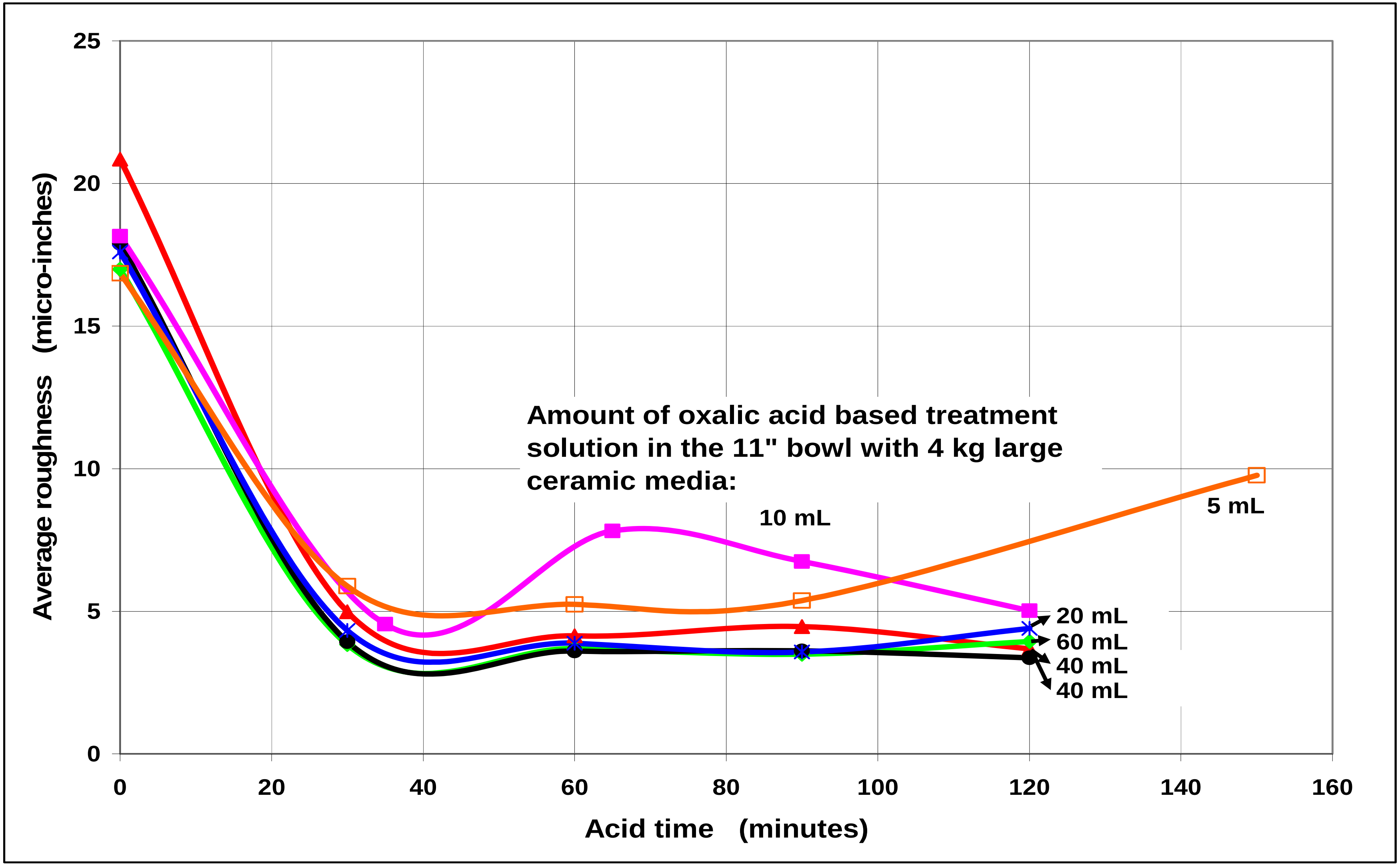
Average roughness versus acid time for different amounts of pyrophosphoric acid.



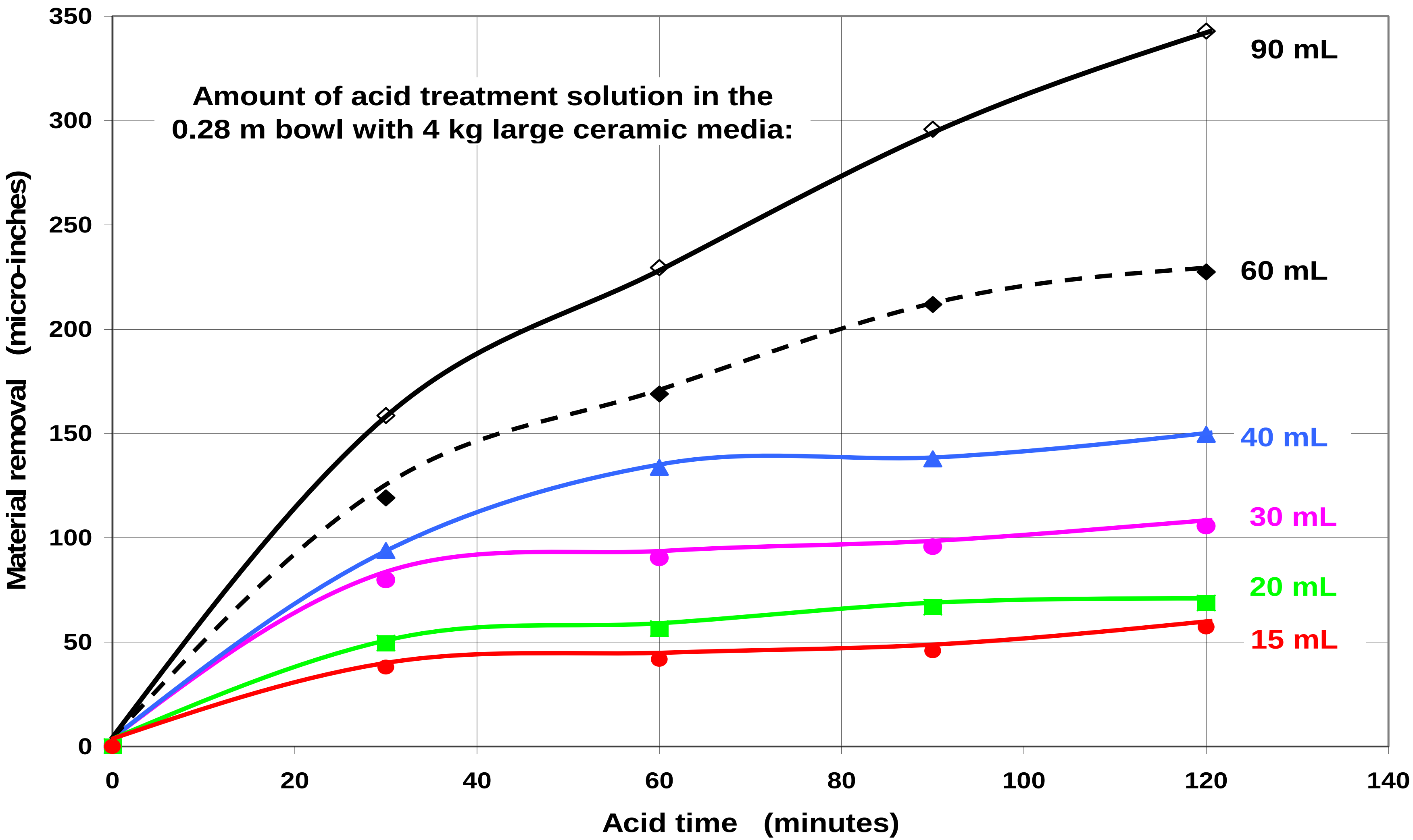
Material removal versus acid time for different amounts of oxalic acid.



Average roughness versus acid time for different amounts of oxalic acid.



Material removal versus acid time for 0.2 M sodium bisulfate, 0.2 M iron (II), 0.2 M iron (III) (sulfate based).



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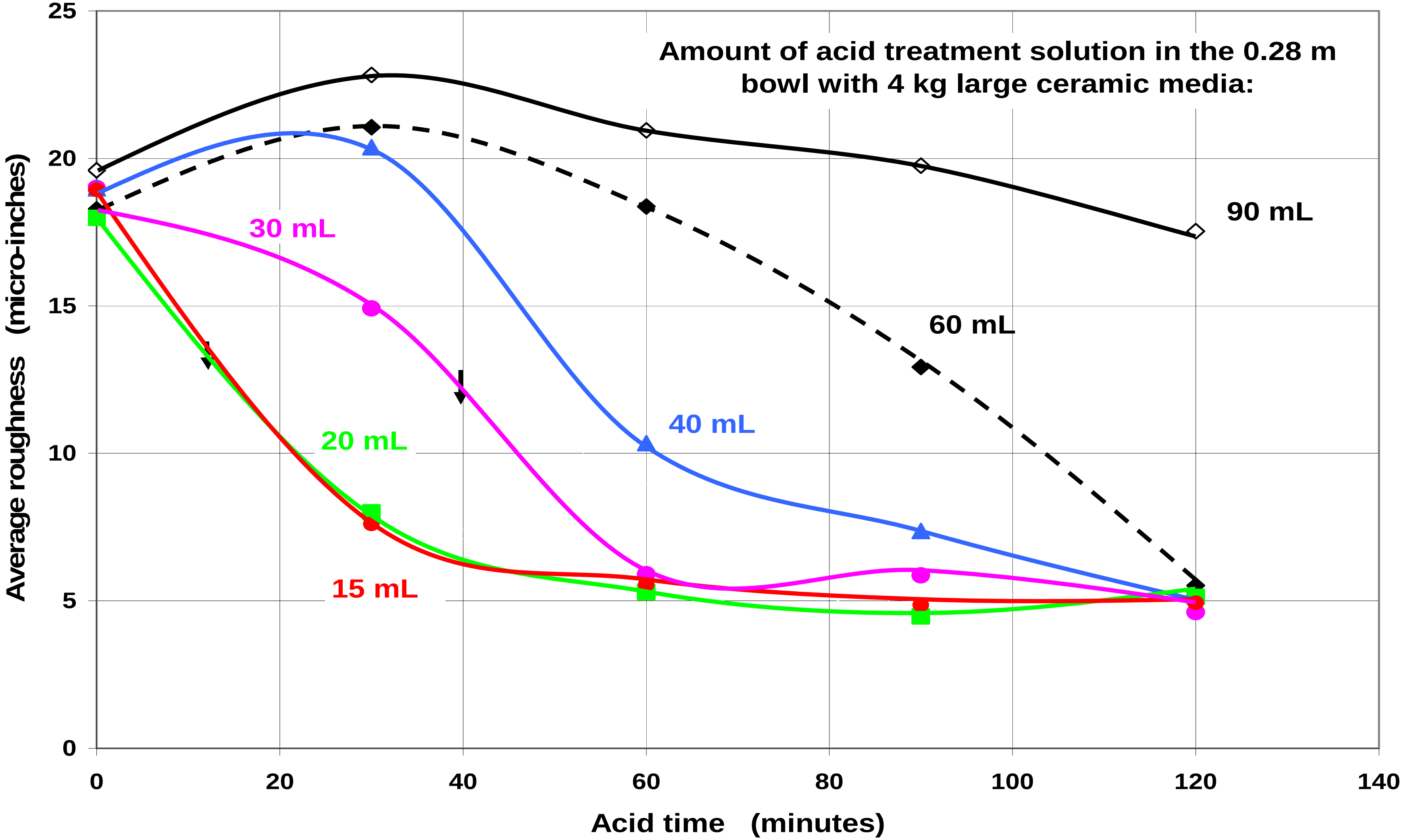

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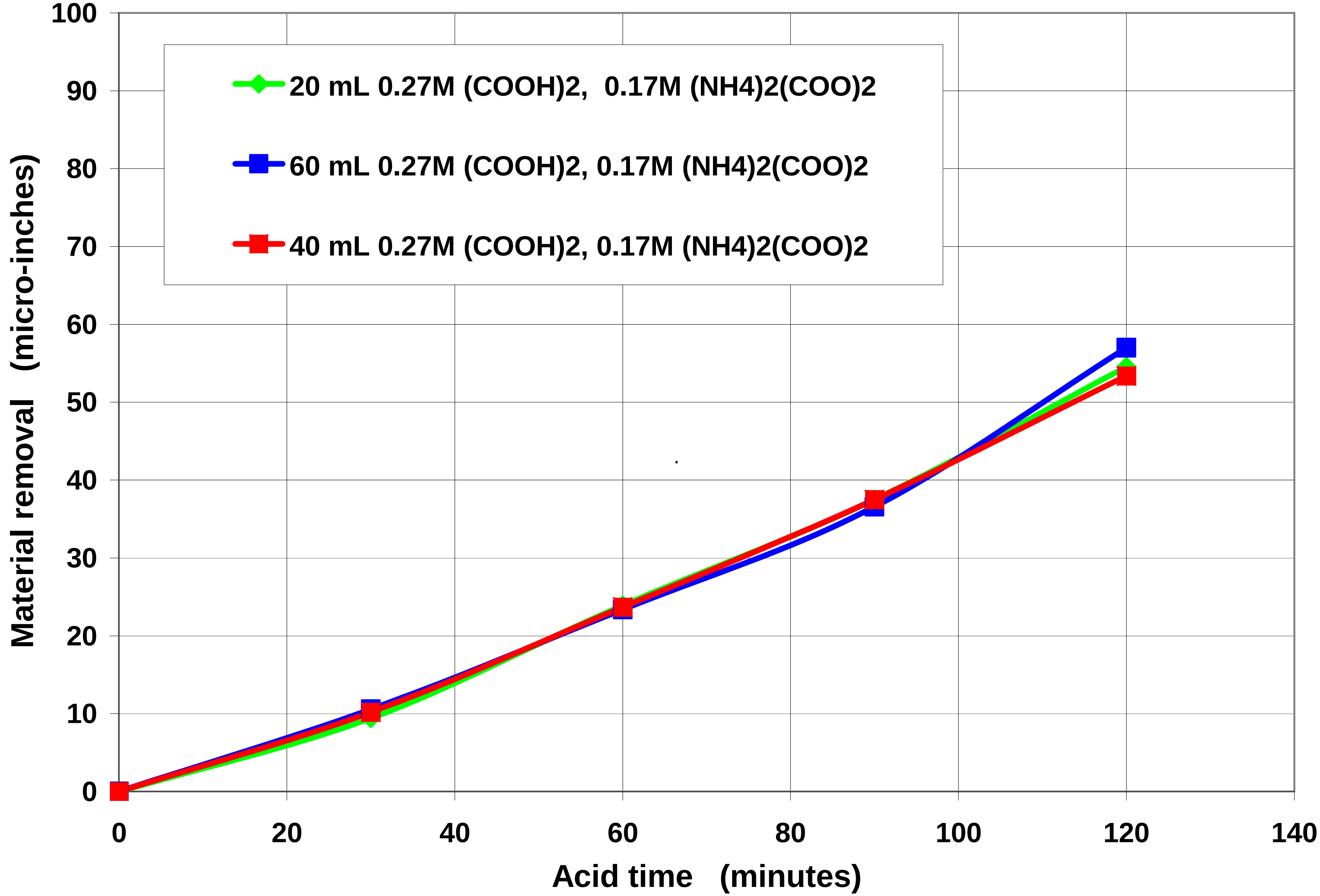
Material removal versus acid time for various amounts of a solution containing 0.27 M oxalic acid, 0.17 M ammonium oxalate



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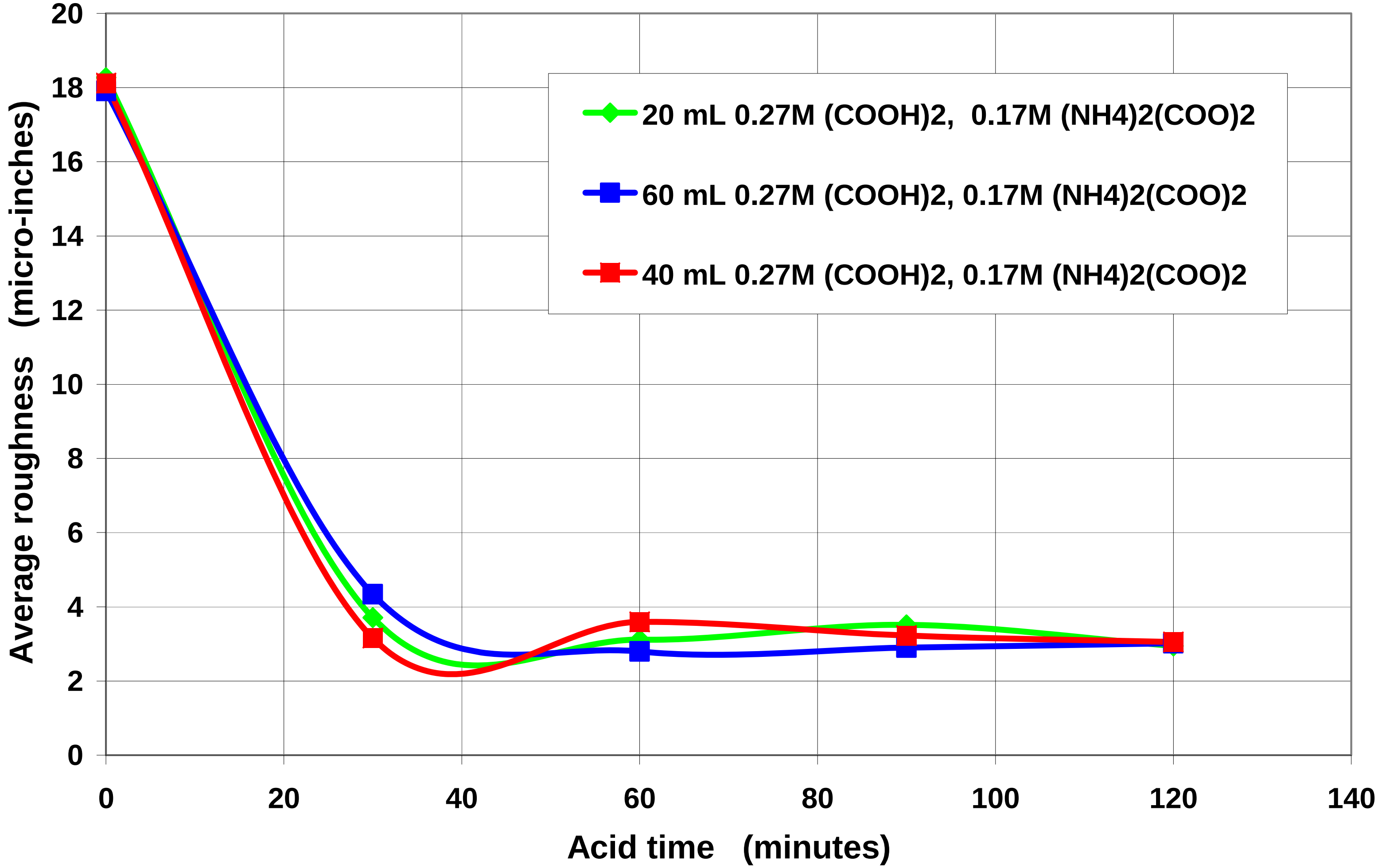
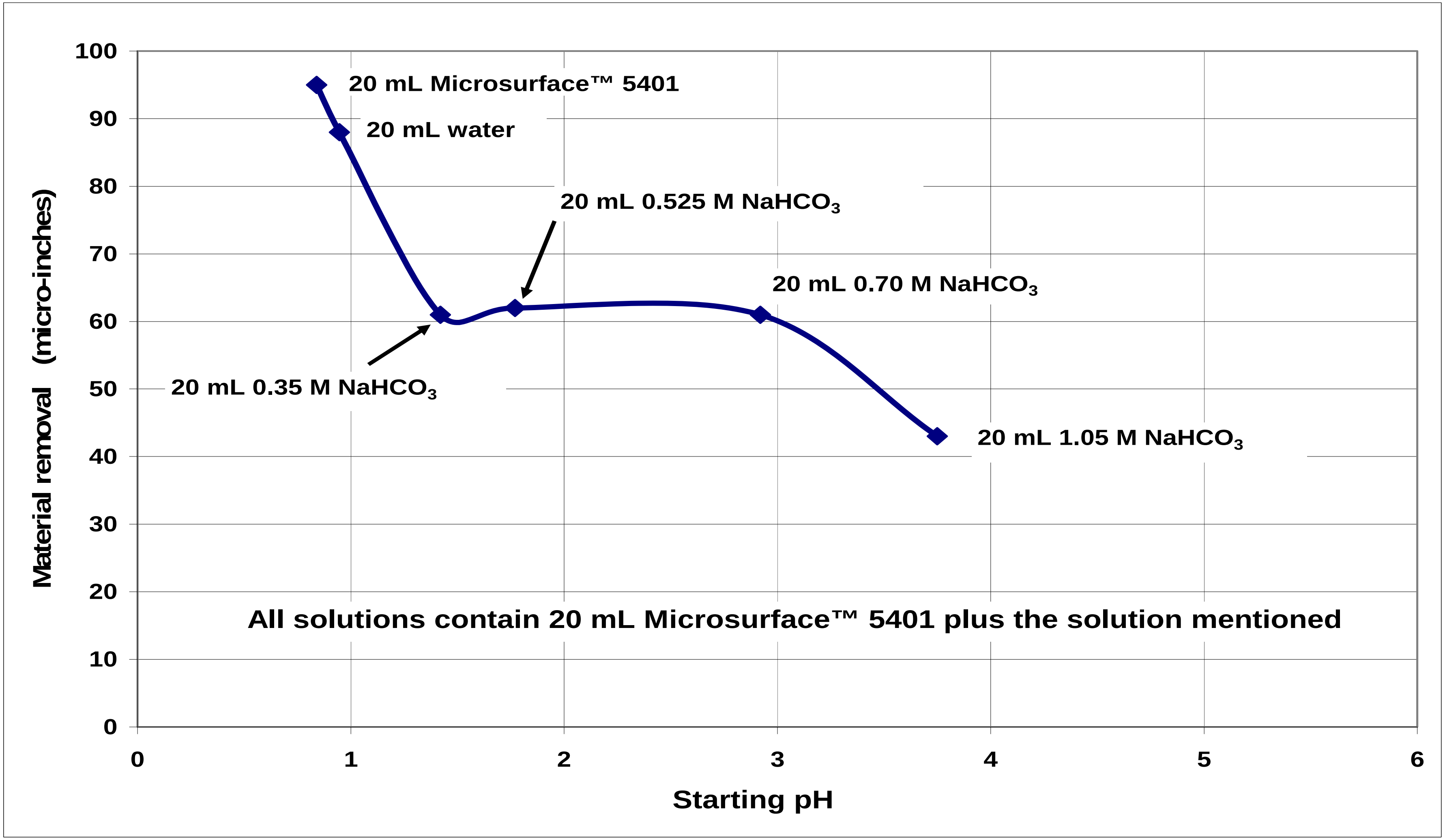


Material removal versus starting pH for different mixtures of oxalic acid based treatment solutions.



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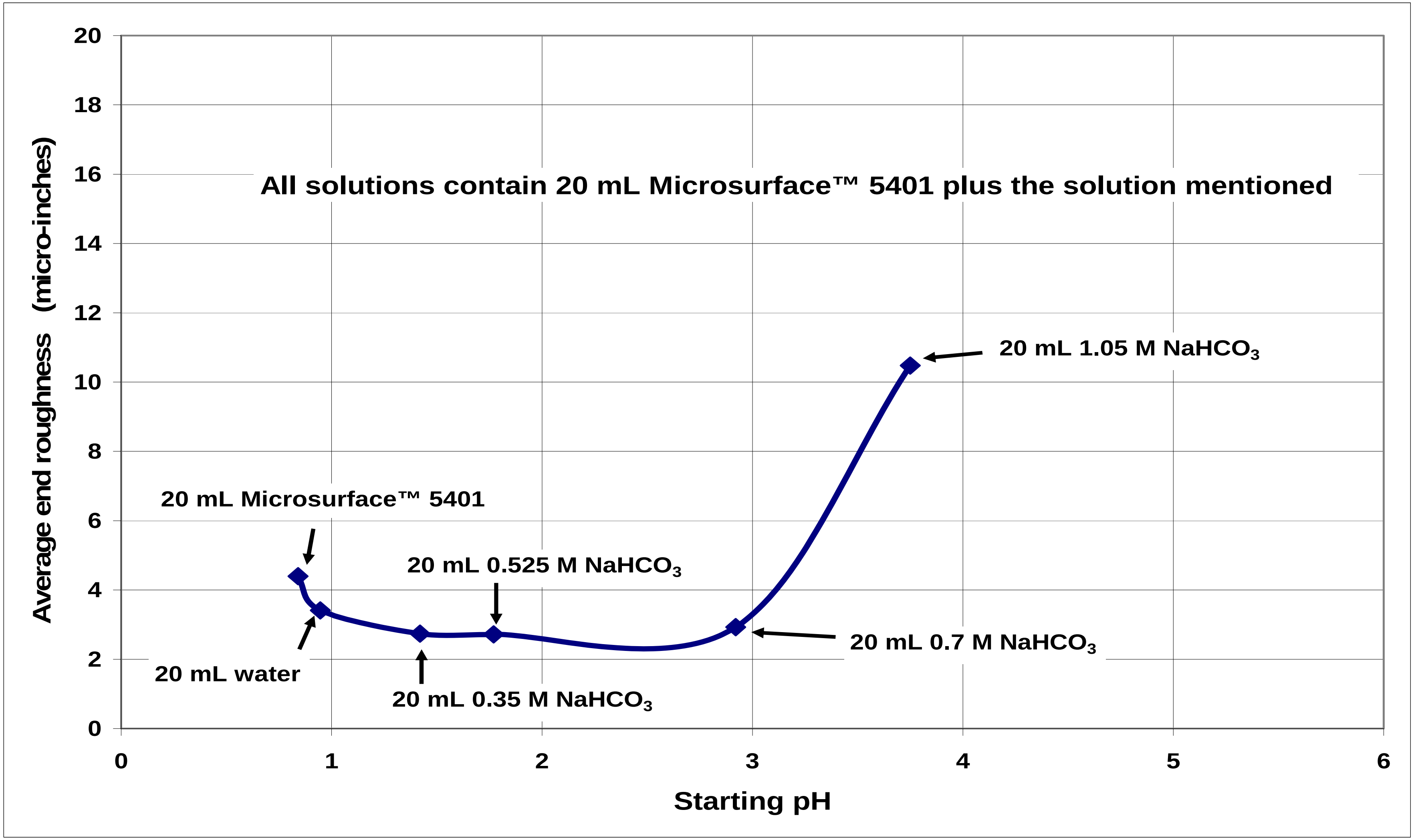

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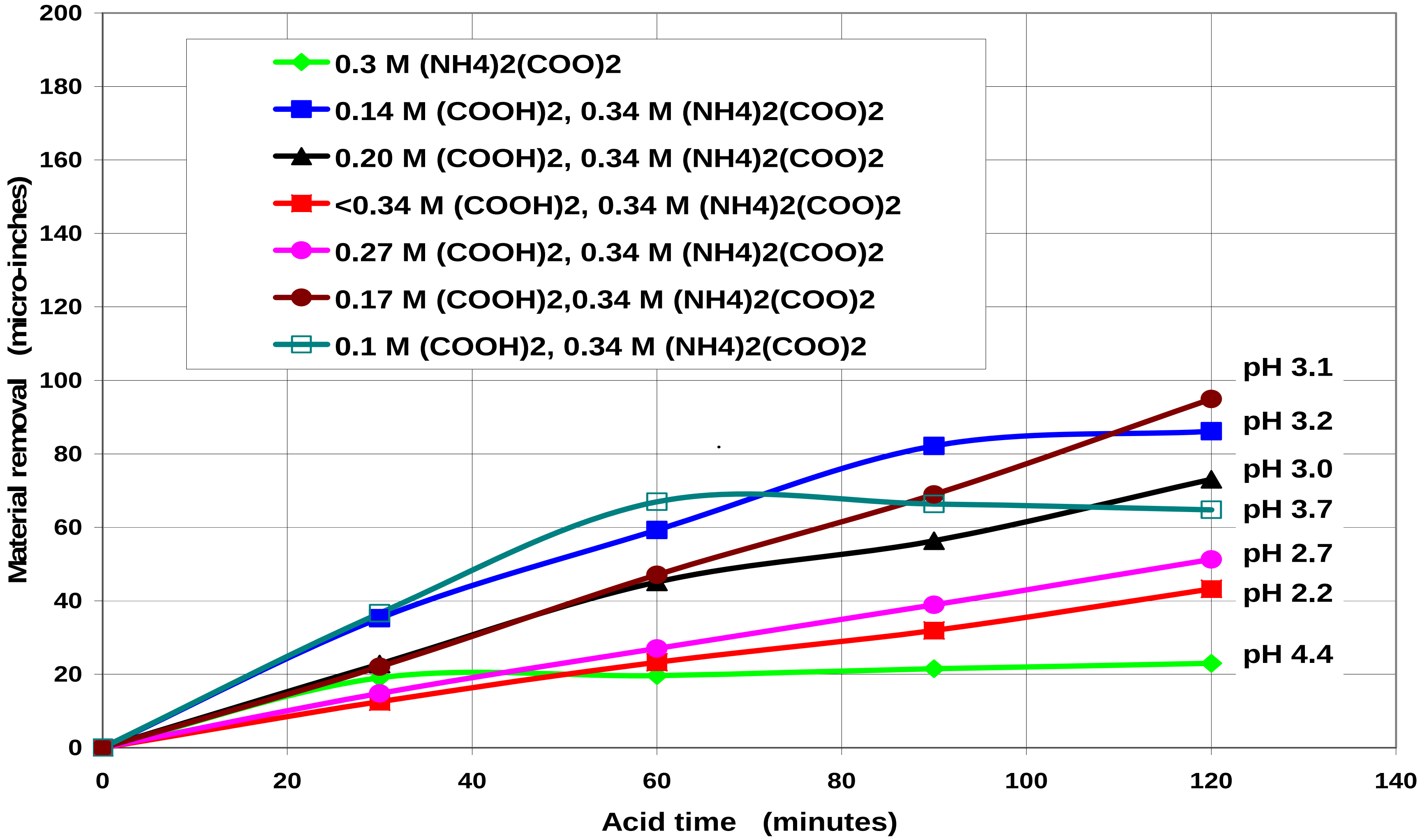
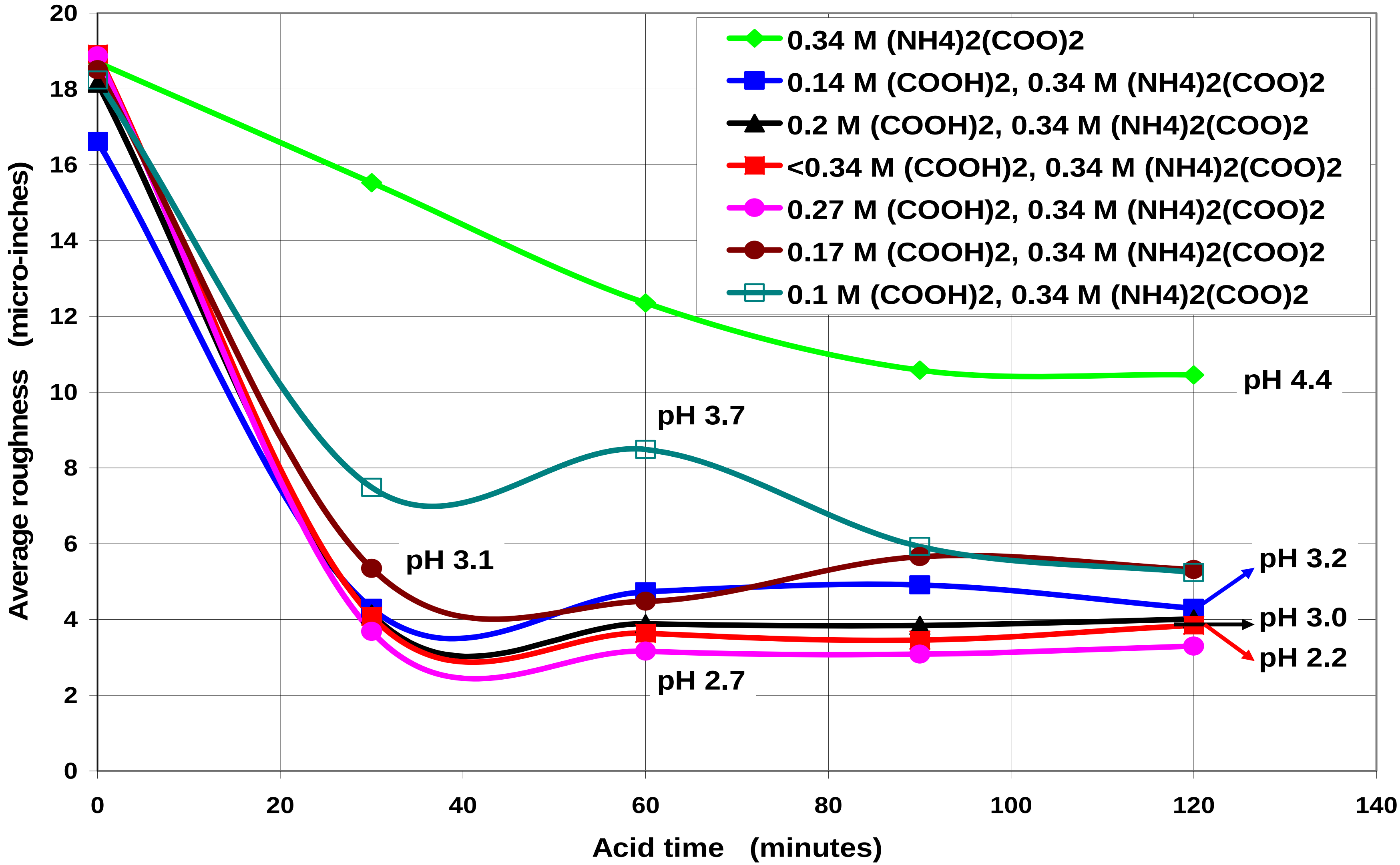
Material removal versus acid time for ammonium oxalate solutions with oxalic acid.



Average roughness versus acid time for ammonium oxalate solutions with oxalic acid.



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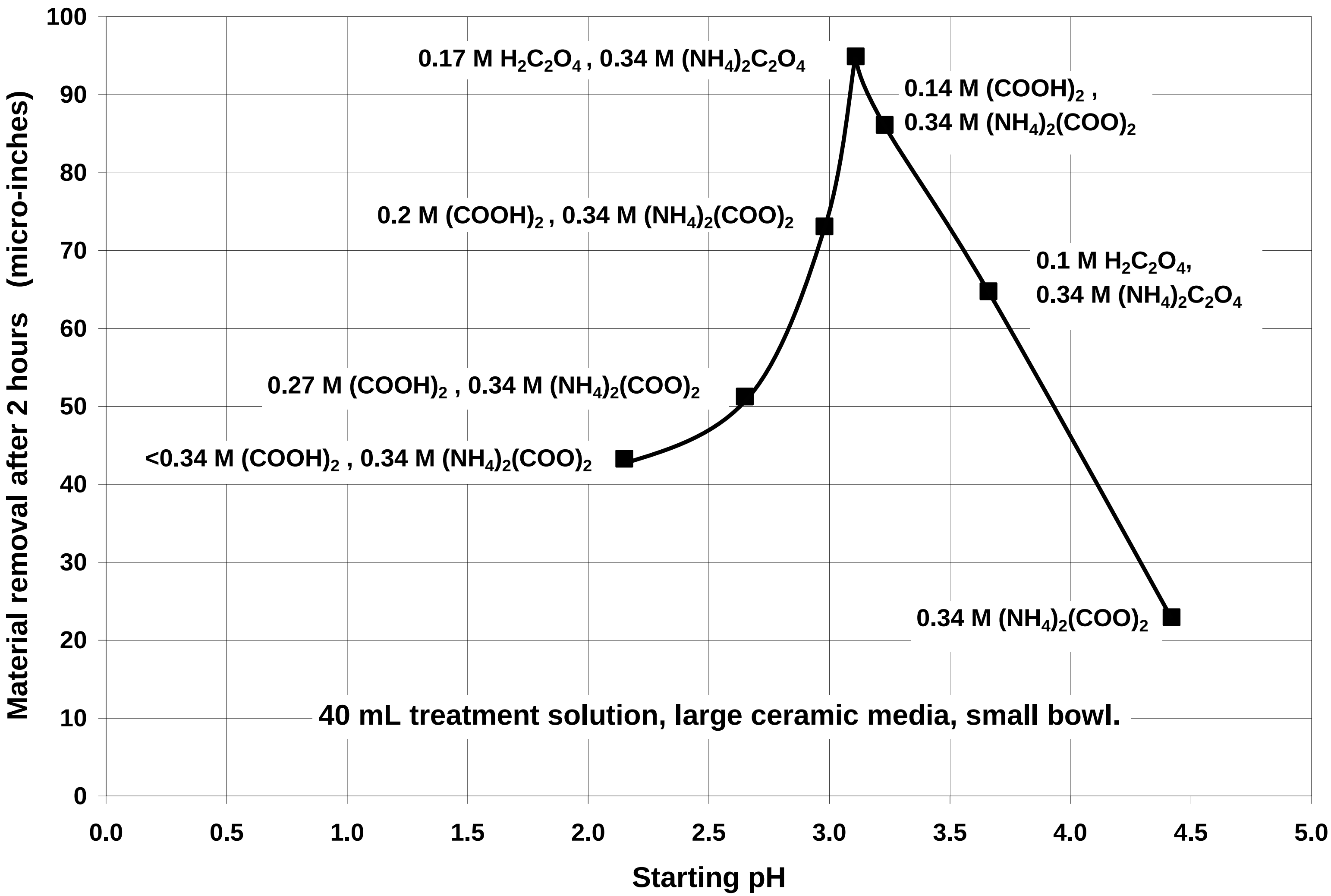
Material removal versus starting pH for 0.34 M ammonium oxalate solutions with oxalic acid.



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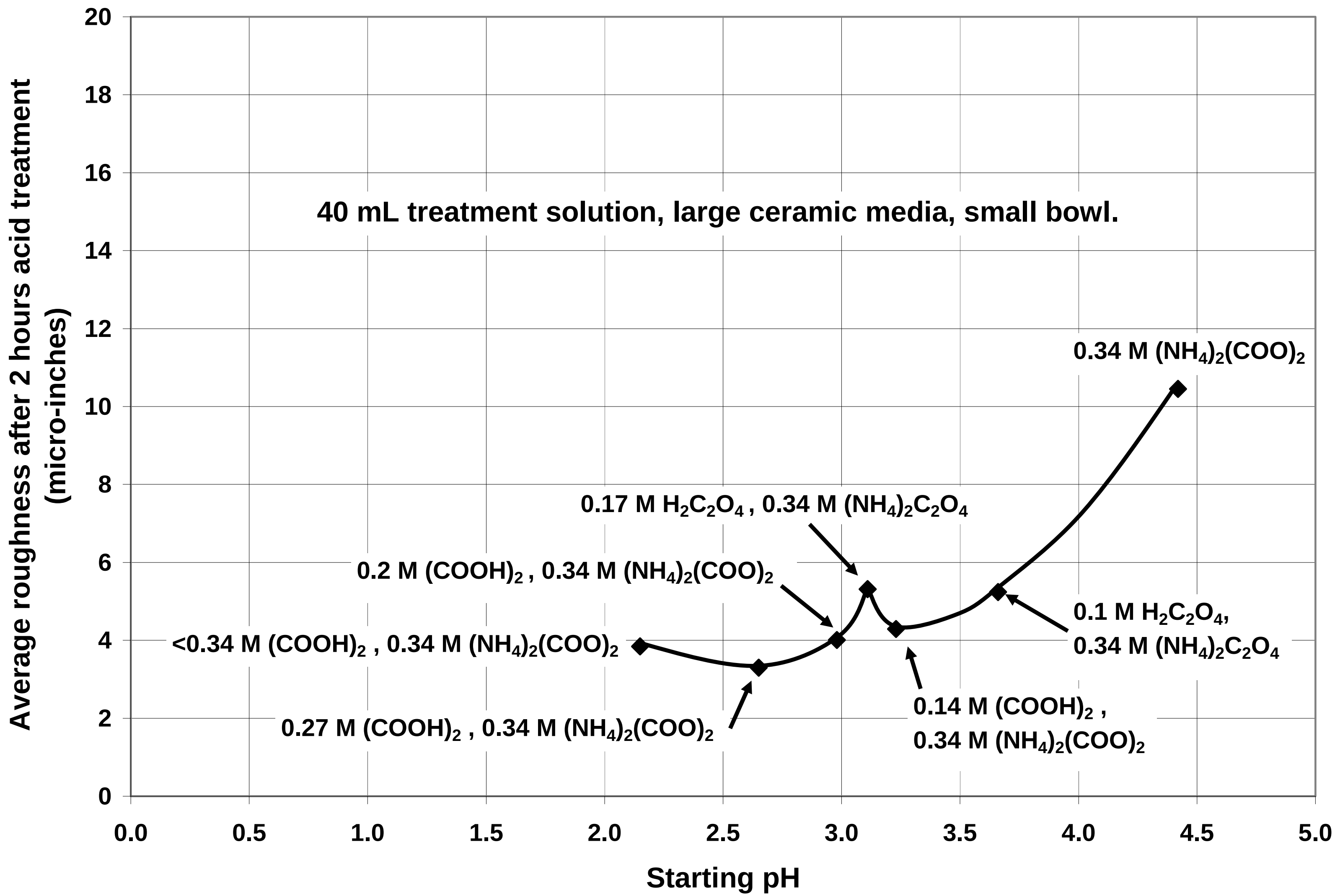
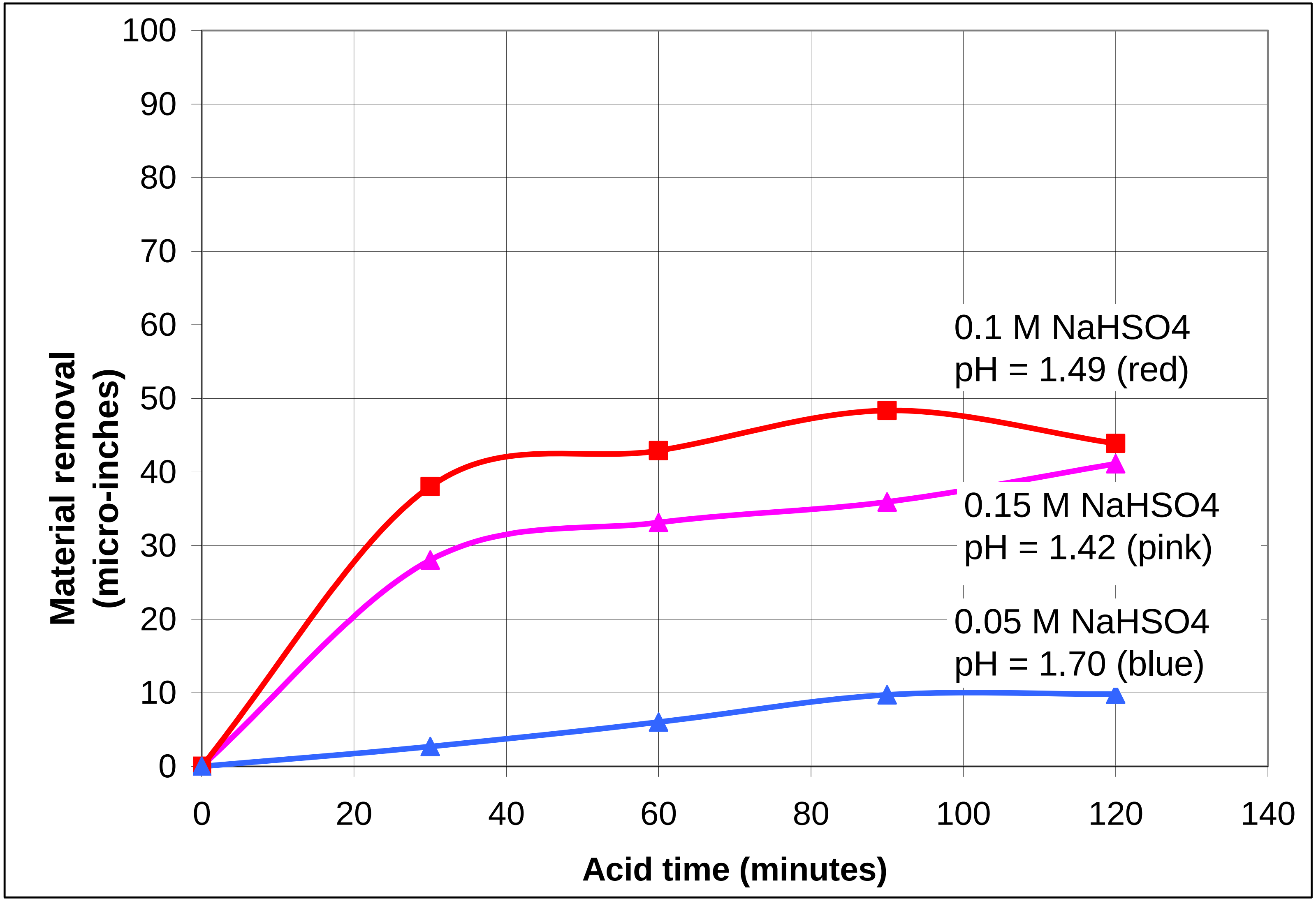
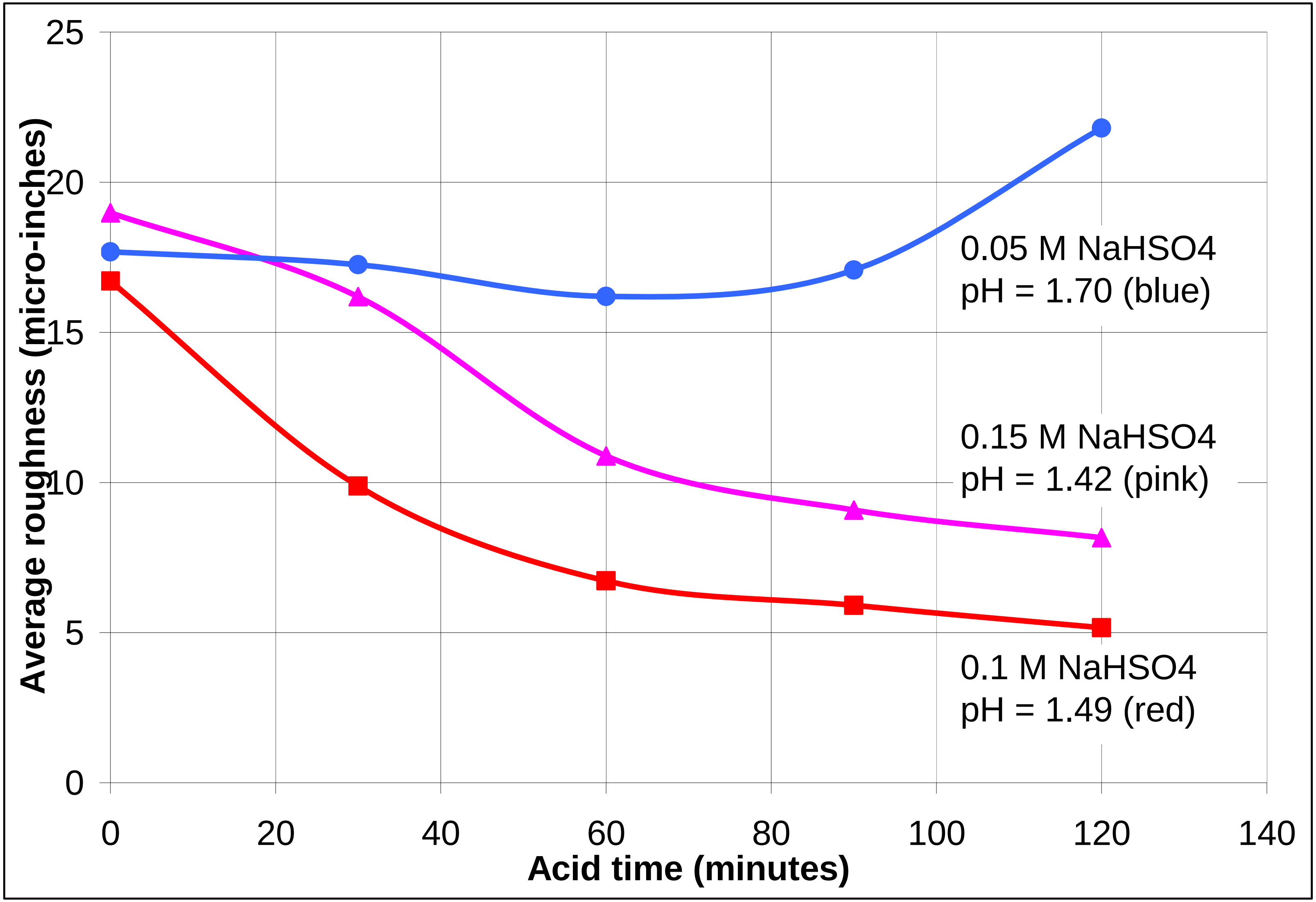
Average end roughness versus starting pH for 0.34 M ammonium oxalate solutions with oxalic acid.



Material removed from strip steel samples vs. acid time for different sodium bisulfate solutions.



Average roughness of strip steel samples vs. acid time for different sodium bisulfate solutions.



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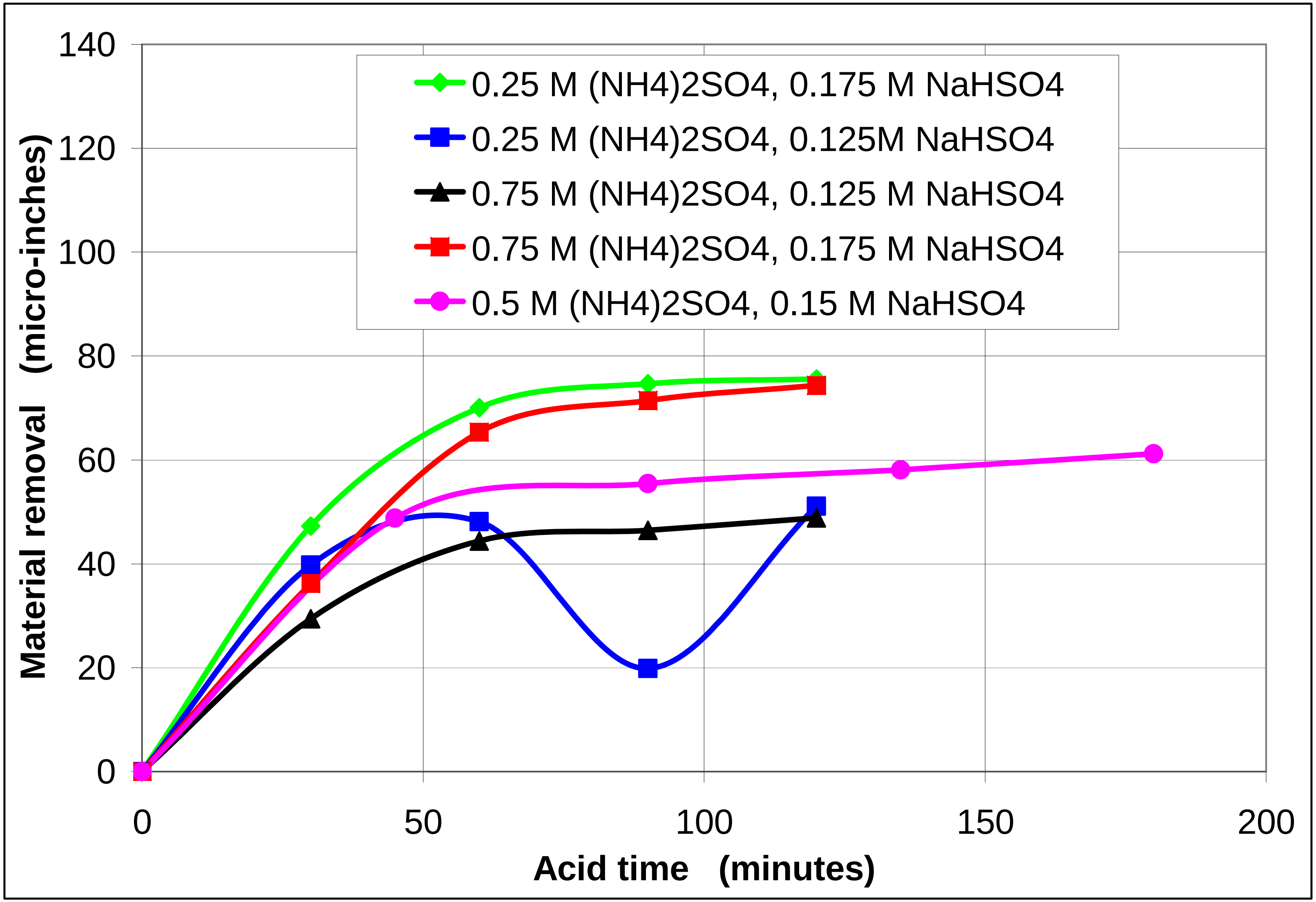
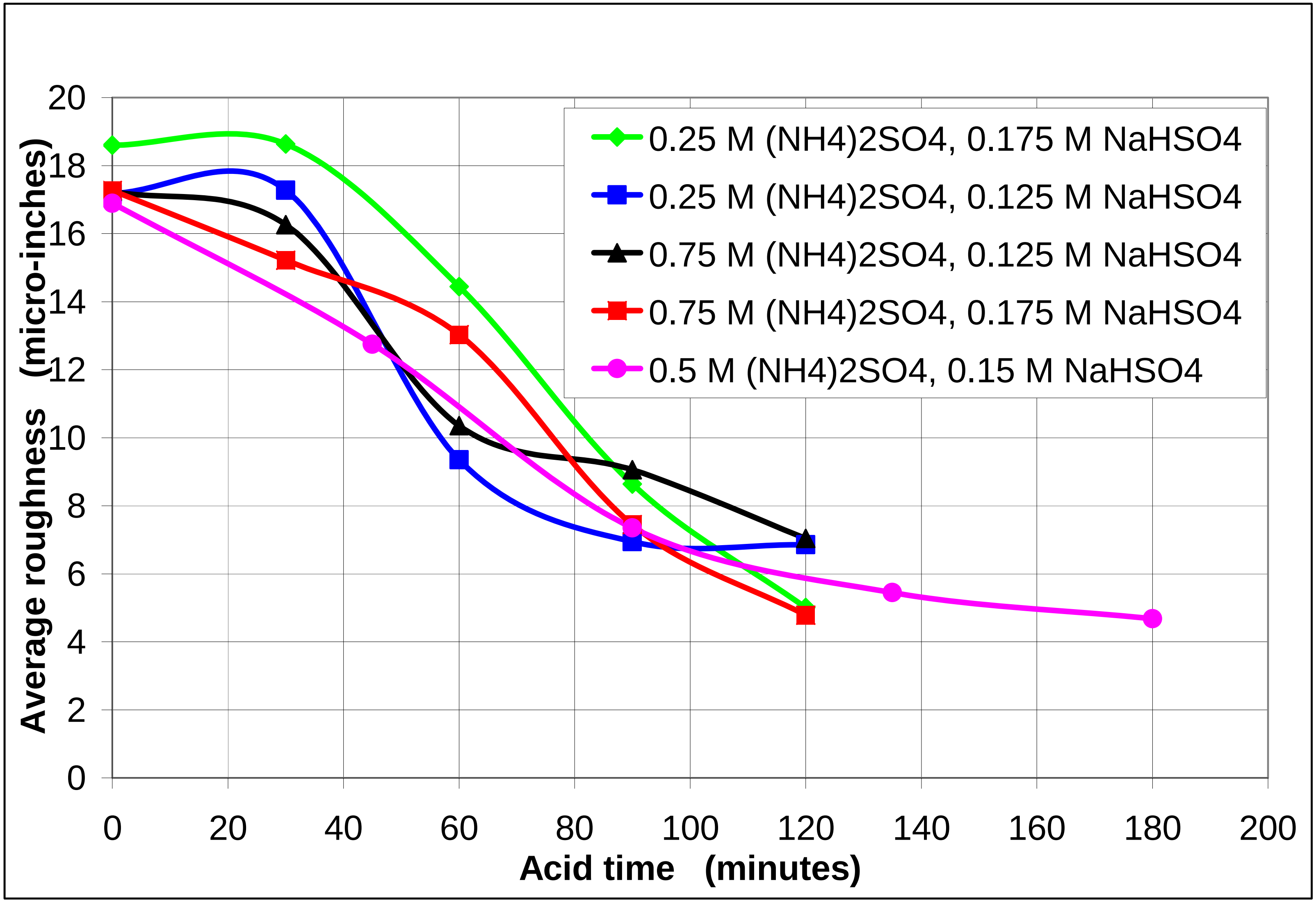
Material removed from strip steel samples vs. acid time for different buffered sodium bisulfate solutions.



Average roughness of strip steel samples vs. acid time for different buffered sodium bisulfate solutions.



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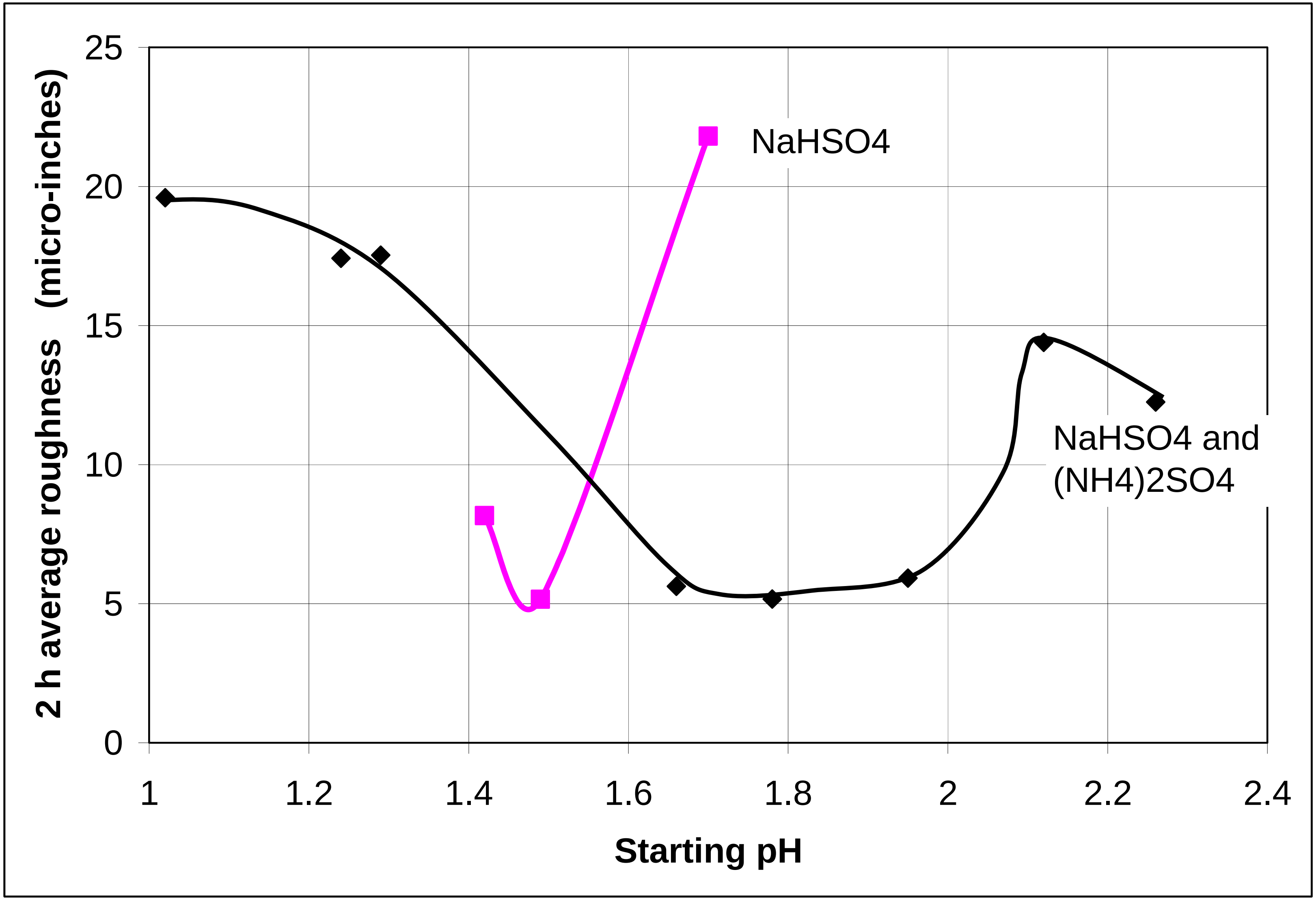
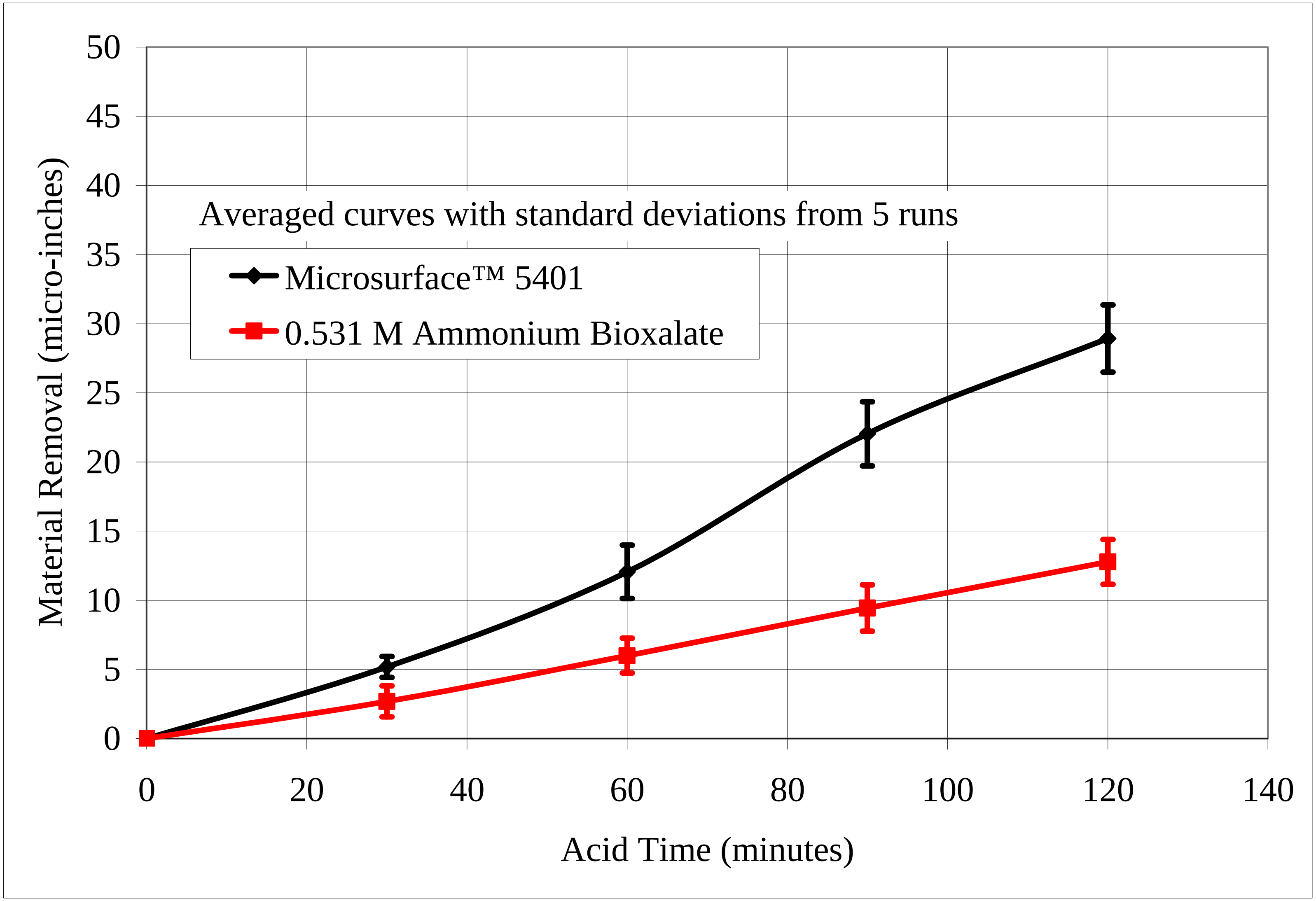
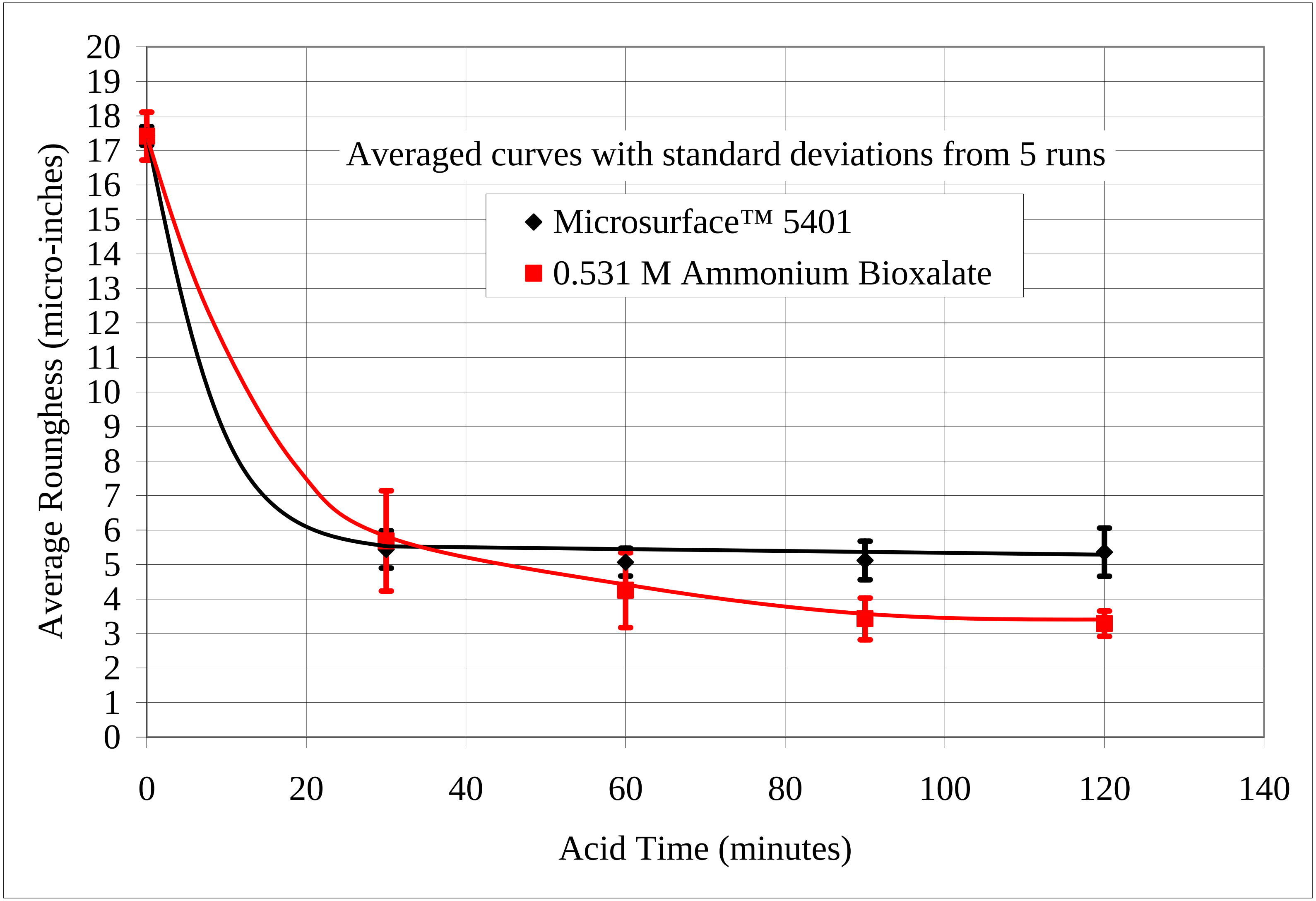
Average roughness after 2 h acid treatment vs. starting pH of the acid.



Material removal versus acid time in the 0.28 m vibrating bowl



Average roughness versus acid time in the 0.28 m vibrating bowl



US Army Benét Laboratories, Alion Science and Technology, and the Engineered Surfaces Center of the University of North Dakota are working together in improving life and performance of materials used for weapons systems.

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Thank you for your attention!

Questions?

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